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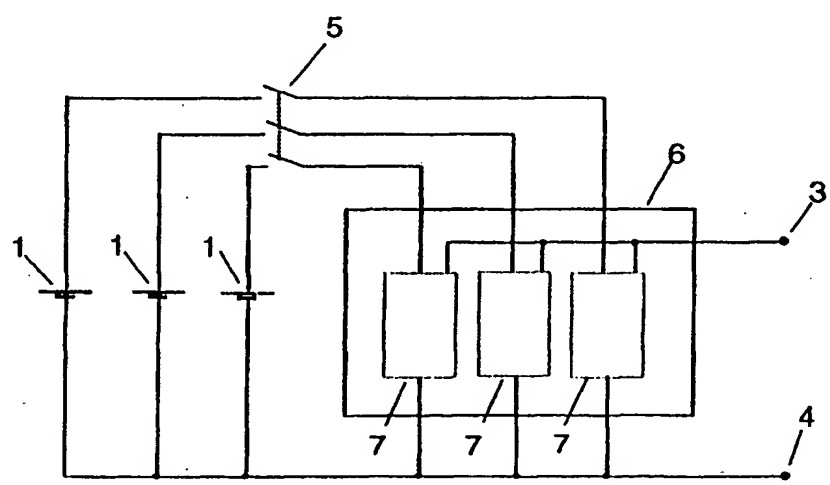


(57) Abstract

A power management system is provided, which can be used with batteries, in which electronic converters (6) extract the total amount of power required from a plurality of batteries (1) arranged in parallel and boost the battery voltage to the voltage required by the load. Thus it is not necessary to connect batteries in series to obtain a greater voltage than can be provided by one battery. Since the output of all the converters (6) is combined to supply the load, each battery can be used independently of the others and thus all batteries may be fully exhausted before being discarded or recharged. The user can be advised of the state of each battery and may therefore change batteries when they become exhausted before all the batteries are exhausted. Rechargeable batteries may be used together with dry batteries and the system conroller may be instructed to use rechargeable batteries preferentially using dry batteries only when no other source is available.

A POWER MANAGEMENT SYSTEM

The present invention relates to an apparatus for and method for power management, and in particular to an apparatus for using batteries in battery powered equipment which enables all the batteries to be fully used and a mixture of battery types to be used at the same time.

Electronic or electrical apparatus which is battery powered often requires more voltage than can be provided by a single cell, which is typically 1.5 Volts for a dry (primary) battery or some other similar voltage for a rechargeable (secondary) battery (e.g. 1.2 Volts for a Nickel Cadmium rechargeable battery). To achieve the required voltage to power the apparatus, it is common to connect a number of single cell batteries in series so that the total available voltage is the sum of their individual voltages.

Using cells in series to provide the power at the voltage required by the electrical or electronic apparatus has a number of disadvantages. When one of the cells has been emptied of energy, its terminal voltage will collapse to a low value. Thus the total output voltage provided by the series chain of cells may fall below the value needed to power the apparatus effectively. If the batteries used are primary (dry) batteries, the user is likely to throw away all the batteries and replace them with new ones. Thus the batteries which still contain some useable charge are thrown away along with the one which is discharged, so that some batteries are not fully used. If the batteries are rechargeable batteries, the user is likely to remove all of them for recharging. It is well known that rechargeable batteries lose their ability to hold charge with age and with use. It is also known that some types of rechargeable batteries (e.g. Nickel Cadmium batteries) exhibit a "memory effect" by which it is meant that if they are not fully discharged their capacity is reduced to the amount by which they were discharged. If the series string of rechargeable batteries are of mixed capacity (due to age and number of cycles experienced by each battery) there is a tendency

in the case of the type of cells which are prone to the memory effect for all the cells to assume the capacity of the cell with the smallest capacity.

A further disadvantage of using batteries in series is that the user is usually given little indication that the batteries are about to cease to be able to power the apparatus until the apparatus ceases operating. The apparatus is therefore out of use until the user can obtain new dry batteries or recharge the batteries if rechargeable batteries are used.

A further disadvantage of using batteries in series is that in order to use the batteries for as long a time as possible despite their voltage declining as energy is extracted, it is common practice to design the apparatus so that it will work with a considerably lower voltage than the voltage obtained from the series chain of batteries when the batteries are new or recently charged. This often means that the electric or electronic circuits in the apparatus effectively throw away the energy associated with the voltage difference between the actual voltage supplied by the batteries and that needed by the apparatus. For example, a dry battery will give 1.5 Volts when new but may still contain useful energy when its terminal voltage has fallen to 0.9V. Four batteries connected in series will therefore give between 6.0 V and 3.6V. If the apparatus needs, for example, 100mA of current to work, and it is designed to work with 3.6 Volts and to discard excess voltage, 240mW of power will be wasted when the batteries supply 6.0V

A further disadvantage of using batteries in series is that all batteries have to be used whenever the apparatus is in use. More energy can be extracted from some types of cells if they can be rested at critical times. However, this is not possible except by switching off the apparatus completely.

According to a first aspect of the present invention, there is provided a power management apparatus for drawing power independently from a plurality of power sources, in which at least one electronic converter is connected to one of the power sources so as to draw power

from the power source, voltage convert it to a desired value and to make it available for supply to a load.

It is thus possible to provide an apparatus which enables power to be drawn from each individual power source, for example a battery fitted into the apparatus, regardless of the state of charge of the other batteries, so that each battery may be used until it is fully discharged. The invention permits the required voltage to be obtained from any number of single cells by boosting the voltage of each cell electronically to the value required. The power obtained from each of the cells is combined to provide the total power required by the load. Thus any number of batteries in any state of charge may be used to provide power to the load.

Advantageously an apparatus including a power management apparatus according to the present invention can operate with any number of batteries fitted so that whereas in the series arrangement all batteries have to be inserted in the apparatus to permit the apparatus work, the invention permits the apparatus to function so long as at least one battery containing useful charge is inserted.

Advantageously the power management apparatus associates each power source with an individual converter such that power sources, for example batteries, of different voltages can be used together. This also permits different types of battery to be used together in the apparatus. For example dry batteries and rechargeable batteries may be used together. Additionally or alternatively batteries of different sizes and capacities to be used together, and/or energy sources other than batteries may be used together with each other or with batteries. For example photo-voltaic panels may be used together with batteries.

Preferably the power management apparatus is arranged to draw energy preferentially from one or more of the batteries. For instance, the apparatus can be directed to draw energy preferentially from rechargeable batteries before drawing energy from dry batteries.

Advantageously the power management apparatus is arranged to make available a signal or data representing the state of each battery so that the user can see or determine which batteries have been fully used and therefore need replacing or recharging.

Preferably the power management apparatus is arranged to permit any of the batteries in use to be rested, with the other batteries taking up the load, so that the rested batteries may recover. Thus the apparatus may monitor the terminal voltage across each battery and use this information, possibly in conjunction with input data or estimated data concerning battery type, to determine when a battery should be rested in order to increase the amount of useable energy that can be extracted from the battery.

Advantageously the power management apparatus is arranged to permit batteries to be changed without switching off the apparatus.

It is thus possible to provide a power management apparatus that delivers from the batteries and their associated converters a supply of constant voltage regardless of the state of charge of each battery, as long as at least one battery has adequate charge remaining.

Advantageously the power management system has a plurality of outputs, in order that it can permit an apparatus to receive from the batteries and their associated converters a multiplicity of supplies of different voltages so that each part of the apparatus can be powered from a supply which is most appropriate for that part of the apparatus so that some aspect of its operation - for example, its efficiency - can be optimised.

Preferably the power management system is arranged to permit the voltage delivered to the apparatus powered thereby to be varied continuously on command from the apparatus. Thus, at any given moment the voltage delivered to the apparatus may be appropriate for optimising some aspect of operation, for example, the efficiency of the apparatus.

Preferably the electronic converters can also operate with power flow in the reverse direction so that the cells may be charged in a regulated manner using the same electronic converters that are used to control discharge of the cells.

Preferably starting means are provided for starting the converters when all storage batteries are substantially discharged. The starting means may be a power source such as a battery (which may be a dry battery) or a storage capacitor which initiates operation of the converters but which is effectively disconnected from any load once the converters have commenced operation so that the battery used for starting has very little energy drawn from it.

According to a second aspect of the present invention, there is provided a module or battery pack which contains at least one battery, the or each of which has an associated converter circuit so as to draw power from the or each battery, voltage convert it to a desired value and to make it available for supplying a load.

The or each battery may be a single cell device. However multicell batteries where cells are grouped together, either in series, parallel or a mixture of both, may also be used.

Preferably the battery pack further includes suitable control means so that the battery pack becomes essentially a two terminal device with respect to discharging and charging

Advantageously the battery pack is arranged to provide a signal or data representing the number of batteries containing charge. A visual indication may be given of the number of cells containing charge, either on the battery pack or on the consuming apparatus as cells become discharged.

Preferably the converters associated with each cell share a common inductor when buck-boost converter topology is employed. This reduces component count and hence cost.

The storage cells which are grouped together to form a battery pack may continue to have a useful life even if one of the cells has failed.

A power management system according to a first aspect of the present invention, or a battery pack according to the second aspect of the invention, may be arranged to receive power from a plurality of solar cells and be arranged to enable the cells to be operated at their maximum output even when some cells have become weak or are subject to a lower level of illumination than the others.

The above identifies the power sources to be combined as batteries. However, the invention is equally applicable to arrangements in which one or more batteries are replaced by other power sources. For example, one such source may be a solar cell (photo-voltaic generator). A typical combination of power sources might be a solar panel (comprising one or more solar cells in series) and a battery. The converters could draw preferentially from the solar panel but resort to drawing power from the battery when the illumination of the solar panel was insufficient to produce the required level of power. The control loops of the converters can be configured to cause the battery only to provide any shortfall in the power required, with the dry cell providing no power when the solar panel can provide the full load. In an embodiment having a storage (rechargeable) battery, excess power from the solar panel may be used to charge the storage battery. The power sources (referred to generally as batteries) may comprise a solar panel, a dry battery and a storage battery. The converter circuits may be configured to draw power preferentially from the solar panel, the storage battery, and the dry battery, in that order of preference. The benefit of the invention is that there is no transient involved in switching from one power source to another, and that more than one power source may contribute at any time to the output, with the amount which each power source contributes at any time being infinitely variable between zero and the maximum amount which that source can supply at any given time.

All the power sources (referred to as batteries) may be solar cells. In this case, a difficulty of using solar cells in series is overcome. The power output of a series string of solar cells is approximately equal to the sum of the voltages of each cell multiplied by the current capability of the weakest (or most poorly illuminated) cell. If the output of individual cells are combined in the manner of the invention, with each cell having an associated converter, the cells are able to operate individually at their maximum capability, without the weakest cell limiting the performance of the others.

This principle also applies where all the batteries are single storage cells. If in a battery pack, consisting of a series string of cells, one cell fails or becomes weak, the total output voltage of the battery pack may be diminished to an extent that the whole battery pack becomes unusable. In a battery pack constituting an embodiment of the present invention, the failed cell would cease to contribute power to the output and the other healthy cells would take up that load so that the battery pack could continue to supply power normally. The battery pack could, if each cell had adequate power capability, continue to function until all cells had failed. When the battery is recharged, each cell may be recharged individually in a manner most appropriate to that particular cell, and if required an analysis made of the state of health of that cell.

One or more of the power sources may be electromechanical. For instance, a source may be a spring-driven generator or wind driven generator. According to the invention, power demand can be transferred to another source by degrees as the spring power or wind power becomes inadequate. If one of the energy sources is a storage battery, surplus power from the electromechanical source can be used to charge the storage battery.

Additionally or alternatively a manually operated generator may be provided as a source of power. Such a generator can be expected to provide a large electrical output for a short duration as it is expected that a user will soon tire of turning the generator. A power management unit may be arranged to control the relatively rapid charging of a storage device such as a rechargeable battery or a storage capacitor. Storage capacitors have the

ability to accept charge quickly. However, their terminal voltage varies rapidly with their state of charge. However, a power management system can vary its output voltage to the storage capacitor in order to maintain a good charging rate.

In an embodiment of the invention an electronic converter circuit is used to boost the voltage of each battery to the required value. Each battery will usually be a single cell battery typically producing a voltage of approximately 1.5V in the case of dry batteries. However, the battery may contain several cells in series and therefore have a higher terminal voltage than would be the terminal voltage of a single cell. (In this description, the word "battery" is used to denote a battery containing a single cell or several cells in series. The word "cell" is used synonymously with "battery" when the battery contains a single cell.) Each battery has associated with it a converter circuit. The converter circuits have their outputs combined so that all the converters which are active provide power to the load. Each converter provides a certain amount of current to the load, the sum of the currents supplied to the load being equal to the current demanded by the load. In the basic form of the system, a control circuit monitors the load voltage and controls the currents provided by the converters so that the load voltage remains at the desired value. The current provided by each converter may be controlled individually or a fixed proportion of the total current demanded by the load may be demanded from each converter so long as the battery associated with that converter is able to provide power. In a more sophisticated form of the system, a control circuit determines according to user guidance or a predetermined set of rules which converters should be activated and therefore which batteries should provide power at any given time or in any given situation. The control circuit may also provide an indication to the user of which cells are being used, which still contain energy, and which are discharged.

According to a third aspect of the present invention, there is provided a method of extracting energy from power sources, comprising the steps of associating a plurality of power sources with at least one voltage converter, and voltage converting the output of the sources to a desired value.

The present invention will further be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 shows single cells connected in series, demonstrating the manner in which batteries are used conventionally

Figure 2 shows a power management system constituting a first embodiment of the present invention and which uses batteries with energy being extracted from individual cells by converters with the output of individual converters combined to provide the required load power.

Figure 3 illustrates a second embodiment of a power management system constituting an embodiment of the present invention, in which a single converter is employed with a selector switch - manual or electronic - which selects the battery from which power is to be drawn.

Figure 4 shows how an auxiliary battery may be used to power the control circuits of the converters of the arrangement shown in Figure 2.

Figure 5 shows a modification to the arrangement shown in Figure 4 by the inclusion of a self-starting boost converter;

Figure 6 shows a further modification to the arrangement shown in Figure 4;

Figure 7 shows a further modification to the arrangement shown in Figure 4;

Figure 8 illustrates a converter using a MOSFET switch;

Figure 9 shows a modification to the circuit of Figure 8;

Figure 10 illustrates a modification to the circuit of Figure 9;

Figure 11 illustrates the combining of the outputs of a plurality of converters to form a common output;

Figure 12 illustrates a single buck-boost converter;

Figure 13 illustrates a modification to the circuit shown in Figure 12;

Figure 14 illustrates a further modification to the circuit shown in Figure 12;

Figure 15 shows a circuit for combining the outputs of buck-boost converters;

Figure 16 illustrates an arrangement where a plurality of converters share a single inductor;

Figure 17 shows the control arrangement when a single battery and converter are used;

Figure 18 shows the control arrangement when a single battery and converter are used and a current control loop is included in the control path;

Figure 19 shows the control arrangement when more than one battery and converter are used;

Figure 20 shows the control arrangement when more than one battery and converter are used and current loops are included for each converter;

Figure 21 shows the manner in which the invention may be used with additional control facilities and state-of-charge indication;

Figure 22 schematically illustrates a battery pack and controller constituting an embodiment of the present invention;

Figure 23 illustrates a battery pack having an integral power management system;

Figure 24 illustrates a modification to the circuit of Figure 23;

Figure 25 illustrates a battery pack constituting an embodiment of the present in which the voltage converters can be used to charge the batteries;

Figure 26 illustrates an arrangement in which a consuming device (Load) includes a start up power source for the voltage converters;

Figure 27 illustrates a two-transistor buck-boost converter;

Figure 28 illustrates a four transistor reversible converter circuit;

Figure 29 illustrates a management system co-operating with a generator and a storage capacitor;

Figure 30 schematically illustrates a variation on the circuit shown in Figure 29, in which a further converter is provided in association with a rechargeable battery;

Figure 31 illustrates a simplified arrangement for utilising a storage battery;

Figure 32 shows a further modification of a management system which allows a battery to be recharged from a generator;

Figure 33 shows a further power management arrangement for use with a generator;

Figure 34 illustrates an arrangement in which a management circuit is used to perform power conversions between a generator, a storage capacitor, a storage battery and a load;

Figure 35 illustrates a modification to the arrangement shown in Figure 34; and

Figure 36 schematically illustrates a converter in combination with a single cell.

Figure 1 shows how single-cell batteries (or other energy sources) are used in the conventional manner. A number of these batteries 1 are connected in series to give the required supply voltage between the positive output terminal 3 and the negative (or zero voltage) output terminal 4. The load is connected across the output terminals 3 and 4. The supply is controlled by a single switch 2.

Figure 2 shows how power is drawn from the batteries and supplied to the load by a power management device 6 according to the invention. A plurality of batteries 1 and corresponding converters 7 are provided. For purposes of illustration in Figure 2 three batteries are shown as being available to provide power. The batteries are connected to the power management unit 6 through a multi-pole switch 5 which disconnects the batteries from the power management unit when the apparatus is not in use. The power management unit contains a number of electronic converter circuits 7, one for each of the batteries 1. The converters 7 boost the power from each battery to the required output voltage. The converter outputs are combined by connecting their outputs in parallel and to the output terminals 3 and 4. Each of the converters is capable of contributing to the current drawn by the load connected across terminals 3 and 4 but not all the batteries 1 need be fitted and not all the converters 7 need to be operated simultaneously. Clearly at least one battery must be fitted and at least the converter associated with that battery must operate to supply the load power.

Figure 3 shows an alternative arrangement of the invention, in which a plurality of batteries are provided (three are shown for the purposes of illustration) but only one converter is

provided. A selector switch 8 is used to select one of the batteries 1 for use. The power from this selected battery is supplied to the converter 7 contained in the power management unit 6 which provides power to the output terminals 3 and 4 at the voltage required by the load. Selector switch 8 may be a mechanical selector switch or it may be an electronic selector switch in which transistors used in the switching mode or relays may be used in place of the mechanical switch. These transistors would then be under the control of an electronic control system which automatically selects the battery from which power is to be drawn.

In the battery management systems shown in Figures 2 and 3 the batteries 1 from which power is to be drawn may in some circumstances not provide enough voltage to operate satisfactorily the control circuits of the electronic converter circuits 7. An arrangement which may be used in this case is shown in Figure 4. The arrangement shown in Figure 4 is substantially the same as that shown in Figure 2 except that the electronic converters 7 have the supply for their control circuits derived not from the batteries 1 but from an auxiliary supply, such as battery 9. The battery 9 may be a single cell or a number of cells in series to give an auxiliary supply of a voltage which will always be sufficient to control the converters and any other control circuits which the apparatus may employ. The battery 9 may be arranged in series with a switch 10 such that it can be isolated once one or more of the converters 7 have commenced operation. The switch may be a solid state switch or a mechanical switch.

If battery 9 is a single cell, the control circuits of the converters will need to be designed to operate with the minimum voltage which this single cell will produce during its useful life. Alternatively, if battery 9 is a single cell, a self-starting boost converter 43 may be provided, as shown in Figure 5, so that a higher voltage power source is available to the control circuits of the converters 7. Battery 9 will always have to have some power remaining so that the converter providing the auxiliary supply will always operate.

The auxiliary battery is connected to the power management unit 6 through a switch 10 which may be ganged with the switch 5.

Once at least one converter 7 is operating and providing an output at terminals 3 and 4, the supply available at terminals 3 and 4 may be used to power the converter control circuits instead of the auxiliary battery 9. The changeover may be effected by the use of a diode-OR arrangement, as shown in Figure 6, in which the positive auxiliary battery output and the converter output at terminal 3 are both connected to the control circuits through forward biased diodes 46. Whichever source provides the highest voltage will cause its associated diode to conduct, while reverse biasing the diode associated with the other source. The auxiliary battery voltage should be chosen so as to be lower than the output voltage at terminals 3 and 4 so that once any of the converters is operating the diode associated with the auxiliary battery will be reverse biased and the converter output will supply the control circuits of the converter and any other system control circuits which may be employed. The battery 9 is thereby relieved of any load immediately the converters 7 start so that the total energy drawn from the battery is very small and the life of the battery is determined mainly by its shelf life. The supply from the output of the converter to its own control circuits may advantageously pass through a storage capacitor and buffering diodes such that a reserve store of power to the converter control circuit is maintained to keep the converter running in the event that the output supply voltage temporarily collapses, for example as a result of abrupt load changes or a brief short circuit occurring.

The auxiliary battery 9 may be a rechargeable battery and provision may be included for keeping this battery charged by diverting some current from the converter outputs to the auxiliary battery. This arrangement is applicable whichever converter topology is used for converters 7. If an auxiliary boost converter 43 is employed, as shown in Figure 5, this can be used in a diode-OR arrangement with the output of the converters 7 as described above and the boost converter 43 shut down when the converters 7 have started running. The boost converter 43 may be connected directly to the output capacitor of the converters 7 (capacitor 17 in Figures 8 and 12) without the need for a diode-OR arrangement. In this

case the control circuits of the converters 7 draw their power from the output of the converters which on starting is pumped up to working voltage by the output of converter 43 which is forced to shut down once the output of converters 7 has reached an adequate voltage to allow the control circuits of the converters 7 to function normally.

Figure 7 shows an alternative to the above starting arrangements. An auxiliary boost converter 44 supplies power continuously at the required voltage to the control circuits of the converters 7. The boost converter 44 draws its input power from the batteries 1. The batteries are connected to the boost converter via respective diodes 45. These diodes perform a diode-OR function and select the battery with the highest terminal voltage. Thus the battery with the highest terminal voltage will supply the auxiliary boost converter 44. The diodes should be chosen to have a low forward voltage drop and the auxiliary boost converter must be capable of operating with the lowest input voltage which this arrangement produces while the batteries still have useful charge remaining.

The switch 5 disconnects all batteries from their converters when the system is not operating. This switch may be omitted if the power semiconductor switches (e.g. the transistors 13 in Figure 8) have sufficiently low leakage in the off-state as to render the use of switch 5 unnecessary. The system on/off switch would then be a single switch which caused the converter control circuits to become active when on, and which prevented the control circuits from drawing current when off.

Figure 8 shows the circuit of the converters 7. The input supply from the battery is applied across the input terminal 11 (positive) and 12 (negative or zero volts). The load is connected across terminals 3 and 4 as described previously. A transistor 13 is switched on and off by control circuit 14. When the transistor 13 is on, current builds up in the inductor 15. When the transistor 13 turns off, the current in the inductor 15 continues to flow through the diode 16 and into the capacitor 17, thus charging capacitor 17. By appropriate control of the relative on and off times of transistor 13 the required voltage is built up on capacitor 17, and thus at the output terminals 3 and 4. The circuit can operate in either of

two well known modes - continuous or discontinuous. In the continuous mode, the current in the inductor 15 declines when the transistor 13 is off but has not reached zero when the transistor is turned on again, so that the current in the inductor always remains above zero. In the discontinuous mode the current in the inductor is allowed to fall to zero during the off-period of transistor 13. These two modes of operation are applicable to all the converter circuits described herein.

To control the operation of the converter, the output voltage is sensed by the control circuit 14 via the voltage signal wire 18 and duty cycle of the switching of the transistor 13 is adjusted automatically by the control circuit so that the average current flowing into the capacitor 17 from the diode 16 is equal to the average current flowing out of terminal 3 into the load, so that the voltage across capacitor 17 remains constant at the desired value. A capacitor 19 connected across the input terminals 11 and 12 provides a local by-pass path for any pulsating components in the current drawn by the converter and reduces substantially the amplitude of any high frequency ac currents which might otherwise be drawn from the battery.

The transistor 13 shown in Figure 8 is a power MOSFET. This type of transistor generally incorporates a reverse anti-parallel body-drain diode. If the battery is fitted the wrong way round, the supply to terminal 11 will be negative with respect to terminal 12. This could cause a large current to flow through the body-drain diode of the MOSFET which could damage the device. This problem may be overcome by using a bipolar transistor for the transistor 13, since bipolar transistors are capable of blocking a certain level of reverse voltage.

When diode 16 in Figure 8 is conducting the forward voltage across it will be of the order of 0.4 Volts (for Schottky diodes or Germanium diodes) to 0.9 Volts (for pn junction silicon diodes) depending on the type of diode used. This forward voltage drop can be a significant cause of loss of efficiency in the converter circuit. To reduce this loss of efficiency, the diode may be replaced by a MOSFET 41 as shown in Figure 9. The

MOSFET structure will incorporate an integral anti-parallel diode - commonly known as the body-drain diode (42 in Figure 9). If the MOSFET is not switched on at any time, the body-drain diode will act in place of the diode 16 in the converter circuit of Figure 8. However, the forward voltage drop across the body-drain diode 42 can be reduced by turning on the channel of the MOSFET at those times when the diode 42 is expected to be in conduction. This practice is well known in power electronics technology and is called synchronous rectification. The MOSFET is selected so that the channel resistance in conduction is such that the forward drop across the MOSFET is considerably lower than that which would appear across a diode when carrying the same current. The usual way of controlling the MOSFET 41 in the circuit shown in Figure 9 is to arrange that MOSFET 41 is on whenever MOSFET 13 is off and vice versa. In place of MOSFET 42 it is possible to use a bipolar transistor though in that case there is no body-drain diode to function in place of the transistor if it is not turned on.

The converter shown in Figure 9 employs an N-channel MOSFET for MOSFET 41. Figure 10 shows how a P-channel MOSFET may be employed in this position so as to offer the possibility of more convenient control of the MOSFETs. For instance, both gates may be tied together so that only one gate driver circuit is required. In general, where diodes are shown as part of the converter circuit, the possibility generally exists to use MOSFETs of either the N-channel or P-channel type in order to reduce conduction losses.

Figure 11 shows how the outputs of a plurality of converters of the type described in Figures 8 to 10 may be combined. Figure 11, for the purpose of illustration, shows two converters with their outputs combined. The output terminals of each converter are connected together so that, with respect to their outputs, the converters are operated in parallel. It will be seen that the capacitors 17 of each converter would thus be in parallel and these can be replaced by a single capacitor 17 in Figure 11. The control wire feeding back the output voltage to the control circuits of each converter (18 in Figure 8) is not shown because when more than one converter is operated in parallel there are a number of

different ways in which each converter may be controlled and these arrangements are illustrated in Figures 17 to 20.

Although a boost-converter is used in the preferred embodiment described above, there are a number of alternative converter circuits which can be used in the power management unit, such as the buck-boost converter, the fly-back converter, and the forward converter. Each of these converters will need to be operated in the well known current mode (either average current control or cycle-by-cycle current control) so that when more than one of each type of converter is used, their outputs can be combined by connecting the output terminals of the converters together so that the converters are operated in parallel with respect to their outputs.

Moving now to the buck-boost type of converter circuit, Figure 12 shows a single buck-boost converter with a conventional diode 160 in the output side of the circuit. The semiconductor switch 13 and inductor 15 are transposed in this circuit compared to their positions in Figure 9.

Figure 13 shows the diode 160 replaced with an N-channel MOSFET 162 used in the synchronous rectifier mode. The buck-boost converter circuit produces an output voltage which is of the opposite polarity to that of the input. However where the sources are low voltage isolated sources (such as batteries) this is unlikely to be a serious drawback

Figure 14 shows the same circuit as Figure 13 but with the diode 160 replaced with a P-channel MOSFET 164 used in the synchronous rectifier mode.

Figure 15 shows how a number of buck-boost converters (two shown here for illustration) may be operated in parallel into a single output capacitor so as to combine the power from a number of energy sources. The converters may be operated independently and continuously

Figure 16 shows how converters can share a single inductor. In this case only one of the switches, 47, may be on at any one time. The inductor is charged with current from one of the sources at a time by activating the appropriate switch. All switches are then off for a period while the inductor delivers its energy to the output. The on-time of each of the switches may be regulated so as to achieve the required power extraction from each battery or power source according to the capability of each power source to provide power and the priority given to each power source. One of the transistors 47 can be switched on and off to the exclusion of all others. Or several of the switches 47 can be operated in a sequenced manner so as to draw power from more than one source at a time. The converter may be operated in the continuous or discontinuous mode. In this circuit it is necessary to employ bipolar transistors as the switching devices since the body-drain diodes of MOSFETs could form a short circuit path between batteries when there was a substantial difference between the terminal voltages of the batteries.

Methods for controlling the converters are now discussed with reference primarily to boost converter circuits although the same basic control principles can be applied to buck-boost converters (taking into account the voltage polarity reversal which occurs with buck-boost converters). Figure 17 shows a basic control circuit for one converter. A voltage signal 25 obtained from terminal 3 of the power unit is applied to a differential amplifier circuit, made up of the differential amplifier 21, the feed-forward resistor 22 connecting the voltage signal to the inverting input of the amplifier, a feedback resistor 23, and a bandwidth limiting capacitor 24 in parallel with feedback resistor 23 between an output of the amplifier and the inverting input. The voltage signal 25 is applied to one end of the feed-forward resistor 22 of the differential amplifier circuit while a reference voltage 20 is applied to the non-inverting input 26. The amplified error signal from the output of the amplifier 27 is supplied to a non-inverting input 31 of the comparator 28. A sawtooth or triangular waveform 29 is applied to the inverting input of the comparator. The output of the comparator is thus a Pulse-Width Modulated signal 30 with a variable duty cycle. This signal 30 is used to control the switching of the transistor 13 in the converter 7. When the output voltage at input 25 is low compared to the reference signal 26, obtained from the

reference source 20, the error voltage will be high. This will increase the amount of on-time in the PWM waveform 30. This will raise the output of the boost converter circuit. Eventually a new equilibrium will be established with the desired output voltage at the output terminals of the converter. The reference signal 25 will generally be a fixed voltage. However, in some circumstances, it may be convenient to permit the output voltage of the battery management system to vary during operation under the control of a variable voltage signal applied in place of the fixed reference signal 25. This signal may be derived from the apparatus to which power is being supplied, and controls the voltage supplied to the load in order to optimise some aspect of the performance of the apparatus (for example efficiency).

Figure 18 shows an alternative control circuit arrangement for one converter. A current control loop is interposed between the output 27 of amplifier 21 and the input 31 of the comparator 28. This current loop is supplied with a current signal 34 from a current transducer (which may be a resistor) which senses the value of the current at an appropriate point in the boost converter circuit. The current may be sensed in the inductor 15 or in the transistor 13. The error signal 27 becomes a current demand signal and this signal is applied to a non-inverting input of a differential amplifier 32. The current feedback signal 34 is applied to the feed-forward resistor 33 which is connected to the inverting input of amplifier 32. A feedback resistor 36 in parallel with a capacitor 35 is connected between the output of amplifier 32 and its inverting input. The amplifier 32, amplifies the difference between the demanded current and the sensed current and sends an error signal to the non-inverting input 31 of the comparator 28. A low value of current signal 34 which is below the current demand signal 27 will cause a high value of error signal to be applied to the input 31. This increases the on-time of the PWM waveform 30 and increases the output from the boost converter until an equilibrium is established. The advantage of the insertion of the current loop in the control circuit is that, in control theory terms, a pole is removed form the major control loop so that it is more easily stabilised.

Figure 19 shows how the control circuit shown in Figure 17 may be extended to include the case when more than one converter is employed to enable power to be drawn from a

number of sources. The PWM output from the comparator 28 is applied to all the transistors 13 in the converter circuits. If any converter is not used because an overall control system has disabled some converters so that particular batteries may be discharged preferentially, or the battery associated with a particular converter has no charge remaining in it, the control circuit will increase the on-time of the PWM waveform 30 so that eventually an equilibrium is reached with the output voltage of the paralleled converters stable at the desired value.

Figure 20 shows how the control circuit of Figure 18 may be extended to include the case in which more than one converter is employed. Each converter has a separate current control loop associated with it. The current control loop being as hereinbefore described. The error signal 27 becomes a current demand signal which is applied to each of the current control loops. The error signal from each of the current control loops is applied to the PWM waveform generators centred on the comparators 28 and 28a. Each comparator 28 and 28a produces a separate PWM waveform 30 for each associated converter 7. If any converter is not used because an overall control system has disabled some converters so that particular batteries may be discharged preferentially, or the battery associated with a particular converter has no charge remaining in it, the major voltage control loop will increase the current demand signal to each of the current demand loops to compensate. The current signals 34 and 34a are different signals each derived from measurement of the current in that particular converter. If a dc component is added to any of these current signals, the associated converter can be delayed form operating until a prescribed level of signal on the current demand signal 27 is reached. Thus a particular converter can be caused to operate at substantially its full duty cycle before any other converter starts to switch. Each converter control circuit will have associated with it an arrangement for limiting the maximum duty cycle with which its switched. When this maximum duty cycle is reached, the current demand signal 27 will continue to rise. At some level it will overcome the current signal bias level of another converter and that converter will also start to operate, and so on, until all converters are operating. By this means power can be drawn preferentially in a preordained sequence from the various power sources. As one power

source reaches its maximum ability to contribute to the output, and that contribution is insufficient to maintain the required output voltage, a second converter will begin to operate - and so on - until all available converters are operating and all available power sources are contributing.

Figure 21 shows how the power management system may be controlled overall. The control system described previously related to the control of the converters and the way in which they extracted energy from the batteries and delivered it to the output at the required voltage. Another level of control may be imposed on the system. This is system management control. Figure 21 shows the system management unit 40 sensing the state of the power sources, in this example batteries, from their terminal voltage via the battery voltage sense wires 37. The system management unit may also receive instructions from control panel switches or a keypad by which means the behaviour of the system management unit may be determined. By this means the system management unit may select one particular battery to use in preference to others until it has been emptied of charge, when it will select another battery for discharge. By this means the sequence in which batteries are used may be predetermined by the instructions given to the system management unit. Or the management unit may be instructed to take energy from one particular source (for example a solar panel) when it is capable of providing power and switching to other sources whenever that source becomes unavailable. The system management unit 40 instructs the individual converters through able/disable signal lines 38 The system management unit may also control an electronic selector in place of the manual selector switch 8 in Figure 3. The system management unit may also include indicator lights 39 or some other visual indicator which shows the user the state of each battery or energy source.

Figure 22 shows a typical embodiment of the invention when the batteries from which power is drawn form a storage battery pack 48. A battery pack conventionally consists of a number of cells in series. In the invention, the battery pack consists of a number of isolated cells 1 with each cell having its own output line while sharing a common return line with

the other cells. The battery pack is connected to the consuming apparatus 49 through some form of connection, 50, which is typically formed by a plug and socket or a set of pressure contacts. Power is drawn from the individual cells of the pack in one of the ways previously described herein. Power may either be drawn from each cell simultaneously, with the load on each cell increasing as cells are emptied, or each cell may be emptied in turn. The advantage of this latter method is that as a cell becomes completely discharged its output voltage will collapse and this can be detected so as to permit the consuming apparatus 49 including a power management controller to provide a visual indication of the proportion or number of cells which have been discharged, thereby giving the user an indication of the amount of power left in the battery pack. The principles set out here apply regardless of which type of converter circuit is used. The battery pack may be recharged by means of a charger which is distinct from the consuming apparatus and which comprises means for charging each cell individually. Additionally or alternatively the converter circuits contained in the consuming apparatus may be made to function in reverse as chargers as described later.

Figure 23 shows how the converters which extract energy from the batteries may be incorporated in the battery pack 48. To allow charging of the individual cells there is a connection 51 provided to each cell which permits the cells to be recharged individually. In addition, there may be low current signal connections 150 to the battery pack to facilitate start-up, condition monitoring and other control functions.

Figure 24 shows how diodes 52 may be incorporated in the battery pack 48 to permit all cells to be recharged simultaneously. Current is fed into the battery pack through the main two terminals, 3 and 4, and is then steered into the individual cells through diodes. Thus the battery pack becomes a device with two power terminals, as is usually the case with rechargeable batteries.

Figure 25 shows how boost converters may also be used in reverse to charge the individual cells when all of the energy sources are individual storage cells. The type of boost

converter used in this case must be that shown in Figure 9 or Figure 10 in which the a MOSFET is used as a synchronous rectifier in place of the diode in the basic circuit. A positive voltage power source of the appropriate voltage is applied to what was previously the output terminals (3 and 4) of the converter arrangement. The MOSFET 41, the body drain diode 53 of MOSFET 13, the inductor 15 and the capacitor 19, form a buck converter. This is a pulse width modulated step down regulator which can be used to control the flow of power from the terminals 3 and 4 to each of the storage cells 1. The channel of MOSFET 13 may be switched on in anti-phase with that of MOSFET 41 if required, so that it operates as a synchronous rectifier, although in the charging mode efficiency may not be of paramount importance. This principle of recharging through the boost converters working in reverse as buck converters may be applied whether the converters are in the battery pack or in the consuming apparatus. Figure 23 shows the situation when they are contained within the battery pack. Then only two high current power connections need to be made to the battery pack, along with whatever signal level connections are required for activation, control and status monitoring.

Signals to activate the converters in the battery pack would need to be transmitted to the battery pack - typically via low current signal connections. If the cells are discharged sequentially, the state of each cell can be relayed via signal connections. Alternatively or additionally the state of the cells can be conveyed via a signal bus using well known system management bus or smart battery management protocols. Additionally or alternatively the state of the cells can be indicated on the battery pack itself by some visual indicator such as one light emitting diode per cell. A switch can be provided on the battery pack to activate these LEDs in the absence of any control signals so that the state of the battery pack can be checked when it is removed from the consuming apparatus.

It will be appreciated that if all cells in a battery pack are substantially flat (discharged), there will be little or no power in the pack to operate the onboard converters. If this is not acceptable, a remedy for this condition is to have in the consuming apparatus a battery (for example a dry cell) which can be used to convey power to the battery pack for the purposes

of monitoring the status of the batteries, either through a separate power line or through the two main battery power terminals. Figure 26 shows how the battery pack 48 may be activated by a battery 9 (for example a dry battery) in the consuming apparatus 49. Closing switch 10 causes the battery 9 to raise the voltage of the power rail 3 to a sufficient voltage with respect to power rail 4 for the converter circuits, which draw their operating power from this rail, to begin to operate. When the converters 7 operate they raise the rail voltage to a sufficient value for the diode 46 to become reverse biased. Further power drain from this battery is prevented. Battery 9 need therefore only ever provide power for a brief instant on start up. To lessen the load on battery 9 during start up some start up arrangement can be provided within the consuming apparatus whereby the consuming apparatus draws no load or a small load during the start up phase. This principle may also be applied when all batteries, including the start-up battery 9, are replaceable single batteries (that is, not contained within a battery pack of like cells). Typically, one battery holder would contain battery 9 while the other battery holders which hold the other cells would contain rechargeable batteries. Battery 9 would be required always to have charge in order to start up the apparatus but the amount of energy drawn from it on start-up would be very small. Where battery 9 is a single cell and has a converter associated with it, this converter could be programmed to shut down as soon as the other converters have started running.

The battery 9 may itself be a converter powered by a single cell. In general, cells and converters may be distributed in any manner between the battery pack and the consuming apparatus as is most convenient for the application. It will be appreciated that battery 9 could be replaced by other storage or generating technologies.

The consuming apparatus may require a number of power supplies of different voltages. Those skilled in the art of power electronics will appreciate that there are a number of ways this can be achieved. A common method is that wherever a converter circuit contains an inductor, that inductor may be tapped at some point along its length to provide a power rail of a different voltage to that of the main power rail. Alternatively, additional converters

(e.g. buck or boost) can be supplied from the main power rail (the output of the main combined converters) to provide additional power rails. These additional converters may usefully share some of the control circuits and power components of the main circuit in order to reduce their cost.

As previously described the converters employed in the aforementioned battery management systems may be buck, boost or buck-boost converters. Figure 12 shows a buck-boost converter of the single-transistor type. A further known type of buck boost converter, which may be employed in the battery management systems, is the two-transistor buck-boost converter. The basic power circuit of this converter is shown in Figure 27.

In the converter, a first transistor 202, an inductor 204 and a diode 206 are arranged in series between an input terminal 200 and an output terminal 208. The ground rail connects input ground terminal 210 to output ground terminal 212. A capacitor 214 interconnects the input terminals 200 and 210. Similarly an output capacitor 216 interconnects the output terminals 208 and 212. A diode 218 has its cathode connected to the ground rail (although it should be appreciated that this ground may, in fact, float) and its anode connected to a node between the inductor 204 and the first transistor 202. A second transistor 220 is connected between the ground rail and the node between the inductor 204 and the diode 206. The transistor switching controller and voltage feedback line (as illustrated for example in Figure 12) have been omitted for clarity.

In operation, transistors 202 and 220 are turned on simultaneously to allow current to build up in the inductor 204. (Transistors 202 and 220 are in this case MOSFETs and in each case the integral body-drain diode is included in the power MOSFET symbol). Then both transistors are turned off and the current in the inductor 204 flows into the output capacitor 216 via diodes 206 and 218. A significant advantage of this circuit is that, unlike in the single-transistor buck-boost converter, the output voltage is of the same polarity as the input voltage (relative to the common ground line). A further advantage of this circuit is

that the output voltage may be greater or lesser than the input voltage and the converter can pass through the transition from one situation to the other without any transient. This ability is particularly useful when the battery voltage is of about the same value as the desired output voltage of the battery management system. Depending on the charge state of the battery, its terminal voltage could be above or below that of the required output voltage. The capacitors 214 and 216 provide paths for AC ripple currents.

Another situation in which this ability to work with a battery voltage which is above or below the output voltage occurs when one of the power sources or "batteries" 1 is implemented as a capacitor. A capacitor can be charged and used as one of the power sources in the battery management arrangement. A particular characteristic of a capacitor is that its terminal voltage varies as charge is removed and the converter type associated with the capacitor needs to be able to operate as required over this range of input voltage, while providing the desired value of output voltage.

The two-transistor buck-boost converter can be made more efficient if synchronous rectifiers are used in place of the diodes . Such an arrangement is shown in Figure 28 where the diode 206 and the diode 218 are replaced by a power MOSFETs 230 and 232, respectively ,of the N channel type. Alternatively P-channel type MOSFETs may be used. The body-drain diode of the MOSFETs (included in the MOSFET symbol) may be used in place of the diodes 206 and 218 and the forward drop across the MOSFETs may be reduced by turning on the channel of the MOSFETs whenever their body-drain diode is expected to be conducting. Current flows through the MOSFET channel in the reverse direction to the normal direction of current flow for the MOSFET. The action of replacing the diodes with synchronous rectifiers has converted the two-transistor buck-boost converter of Figure 27 into the four-transistor buck-boost converter of Figure 28. This converter has the advantages that power may flow in either direction through the converter and that the output voltage may be greater or lesser than the input voltage.

The converter shown in Figure 28 may be viewed as one leg of an inverter (comprising transistors 202 and 232) connected to one leg of another inverter (comprising transistors 230 and 220). Each leg represents a converter of variable output voltage with the capability to deliver or absorb current and therefore to deliver or absorb power. The two legs are linked by an inductor 204 which can absorb the instantaneous voltage difference between the two inverter legs. The converter arrangement shown in Figure 28, hereinafter called the FTRC (Four Transistor Reversible Converter), is therefore capable of power flow in either direction. In addition the output voltage may be greater or less than the input voltage. The switching of transistors 202 and 232 may be entirely unrelated to that of transistors 230 and 220. Each leg of the inverter may be operated in either the buck or boost mode. In addition, the converter may from time to time enter the switching configuration in which transistors 220 and 232 are on while transistors 202 and 230 are off. Alternatively, the converter may enter the mode in which transistors 202 and 230 are on while transistors 220 and 232 are off. These two modes allow current to circulate through inductor 204 and through the two transistors which are on, without power being received or delivered at that time from either the input or output. This allows energy to be stored in the inductor for rapid use independent of the average amount of power being absorbed or delivered at the input or output of the converter at that time.

The use of the FTRC in the battery management arrangement has the additional advantage that the converters can be used to charge as well as discharge the cells batteries or cells associated with them in the manner described earlier, since the FTRC can handle power flow in either direction.

As mentioned earlier, one or more of the power sources may be a capacitor which is charged to some appropriate voltage. The capacitor is therefore the equivalent of a rechargeable battery and the advantages of rechargeable batteries are also relevant to a capacitor as a rechargeable power source. The capacitor has an advantage as a rechargeable power source in that generally capacitors can absorb charge very quickly - that is, a high charging current can be employed - whereas electrochemical storage batteries are limited in

this respect. Some sources of power used for recharging may be able to deliver high power (relative to the allowed recharge power rating of the storage battery) for a short time. For example a hand-cranked generator may give a large amount of power but the user may only wish to crank for a short time. In such circumstances, the energy produced can be stored in a capacitor, which can absorb large amounts of power, and then the energy can be transferred at a more acceptable rate to a rechargeable battery of the electrochemical kind for subsequent use by the load. The transfer of energy from the capacitor to the storage battery may be via one of any of the converter types previously described. The power transfer from the storage battery to the load may then be direct (without the intervention of a converter) or the power may be transferred to the load in a regulated manner via a converter of one of the types previously described.

Figure 29 illustrates an embodiment of this arrangement. Power to charge a storage capacitor 267 is provided by the electromechanical generator 265. If generator 265 is a dc generator with a mechanical commutator the diode 270 will be required to prevent current flowing back into the generator once the capacitor 267 is charged and the generator is no longer generating. Diode 270 may be replaced by a power MOSFET acting as a synchronous rectifier if a lower forward voltage drop is required. The generator 265 may be an alternator followed by a rectifier to convert the ac generated into dc in which case diode 270 is not required since the rectifier diodes will prevent current flow back into the alternator. Power may be provided from the capacitor 267 via a converter 272 of, for example anyone of the types described hereinbefore, to the load which is connected to system output terminals 3 and 4.

Since the self discharge time of the capacitor 267 may be unacceptably short, the energy stored in the capacitor 267 may be transferred to the storage battery 274 as well as or instead of providing power to the load connected to the terminals 3 and 4, as shown in Figure 30. A converter 276 is provided in association with the storage battery 274 and is of the type which can handle power flow in either direction - for example the synchronous rectifier version of the boost converter or the FTRC. It will be appreciated that the

advantage of using a switched mode converter for the power transfer from the capacitor to the storage battery or from the generator directly to the load is that switched-mode power converters have a theoretical efficiency of 100% when all their components are ideal and therefore the power transfer can theoretically be achieved in a lossless fashion.

It will be seen from Figure 30 that power flowing from the capacitor 267 to the storage battery 274 flows through two converters. If an unregulated power output at terminals 3 and 4 is acceptable a single converter (buck, boost, two-transistor buck-boost, or reversible converter) may be used in the arrangement shown in Figure 31 in which the energy from the storage capacitor 267 is transferred to the storage battery 274 through one converter 276. Capacitor 216 provides a by-pass path for ripple currents. The output voltage at terminals 3 and 4 is then only regulated to the extent that the storage battery is able to maintain a constant output voltage

Alternatively, as Figure 32 shows, a second converter 278 can be added between the storage battery 274 and the load so that the load receives regulated power. Capacitor 280 provides a by-pass path for ripple currents. If converter 278 is capable of handling power flow in the reverse direction, the storage battery can be recharged under the control of converter 278 from a source connected to terminals 3 and 4 in the manner previously described.

The output voltage of the generator 265 will be approximately linearly related to generator speed. If the generator is connected directly to the capacitor (through diode 270 if appropriate) the generator speed will have to be increased gradually during charging of the capacitor if the generator voltage is to match approximately the voltage of capacitor which it is charging. The power which the generator delivers is approximately given by the product of the generator terminal voltage and the current which it delivers. If the current which the generator can deliver is limited or the torque available to drive the generator is limited, the power which can be put into the generator and the electrical power which the generator can deliver will be a function of the generator speed which is related, as

described above, to the state of charge of the capacitor 267 at that time. In many cases it will be more convenient for the generator to operate at roughly constant speed whatever the state of charge of the capacitor. This requirement can be met if a switched-mode converter 282 of any of the types previously discussed is introduced between the generator 265 and the capacitor 267, as shown in Figure 33. A capacitor 284 is introduced to provide a path for ripple current. The converter could be of any type but most likely of the buck type since the generator can always be wound in a manner which means that at a convenient speed of rotation it delivers a voltage which is always greater than the capacitor (or battery) voltage. The converter accepts power from the generator at constant current at whatever voltage the generator is delivering. The power is delivered to the capacitor 267 at the terminal voltage of the capacitor at that time. It will be understood that a battery may be used in place of the capacitor 267 if the battery has the ability to absorb the instantaneous power output of the generator without damage or if the converter limits the power delivered to the battery to a safe value, in which case the generator mechanical input power must be correspondingly limited.

The converter 282 in Figure 33 may be controlled in a manner which causes the constant current demand level at the input to be increased steeply at some value of generator output voltage so that if it is a hand powered generator the operator feels a suddenly increasing torque once a predetermined speed is reached. Thus before this point is reached, an increase in generator power is obtained by an increase in generator speed. Above this speed an increase in generator power input is obtained mainly by an increase in torque. Clearly in all situations the output power from the converter will balance input power to the converter (except for losses in the converter)

If the converter 282 which controls power delivery to the capacitor (or battery) 267 is of one of the types of converter capable of reverse power flow previously described, a single converter can be used to control power flow into and out of the capacitor 267. In Figure 33 an optional output lead 286 is connected to the positive terminal of the capacitor 284. This output lead can replace terminal 3 as the positive output terminal of the battery

management arrangement. This lead can go directly to the load, with diode 270 blocking current flow into the generator. Alternatively the generator can be disconnected by a switch when the generator is not being used for charging and converter 282 is delivering power from the capacitor to a load. The voltage on this lead will be unregulated during charging and some provision may need to be made for disconnecting the load during charging. The load may be a storage battery which is being recharged with energy drawn from the capacitor 267.

Figure 34 shows how a single converter 298, typically of the FTRC type, can be used to perform all the power conversion functions in a battery management system in which at least one capacitor and at least one rechargeable storage battery form the "batteries" 1 or "power sources" referred to previously. Multi-way switches 288 and 290 are located on either side of the converter 298 as shown. With switch 288 in position A and switch 290 in position A the generator charges the capacitor 300 under the control of the converter in the manner previously described with power flow from the generator 265 to the capacitor 300. The energy in the capacitor 300 can be transferred to the storage battery 302 when switch 288 is in position B and switch 290 is in position A. Power flow is from the capacitor 300 to the battery 302. Power can be transferred from the battery 302 to the load 304 by putting switch 288 in position B and switch 290 in position B. If switch 288 is in position C and switch 290 is in position A power can be transferred directly from the capacitor 300 to the load 304. Capacitors 306 and 308 positioned adjacent the converted 298 provide a by-pass path for ripple current.

The mechanical switches are not needed if the converter 298 is operated in the appropriate manner. Figure 35 shows how the circuit may be configured without the switches. When the generator 265 is generating, the converter draws sufficient current from the generator to prevent excessive current flowing into the battery 302. Once the capacitor 300 is charged and generator 265 has ceased generating, the converter 298 operates in the reverse direction and energy is transferred from the capacitor 300 to the storage battery 302. At all times the load 304 is connected to the storage battery. The voltage applied to the load 304 is not

therefore regulated to the same degree in other embodiments in which the load is supplied directly from the output of a regulator.

It will be appreciated that many of the battery management arrangements described herein are applicable when the number of batteries (or power sources) involved is one. Figure 36 shows one such configuration. This is effectively a single cell battery pack of the type and arrangement previously described. A battery 310 can be a single cell and power is delivered via a converter 312 which can be a single converter which can advantageously be contained within a housing shared with the battery, forming a battery pack 314 as previously discussed but with a single cell as the power source. If the battery is a rechargeable battery, the use of either the boost converter with synchronous rectifier (Figure 9 and Figure 10) or the FTRC (Figure 28) will permit the battery to be recharged through the two main terminals 3 and 4. The use of a converter for recharging not only permits the battery to be recharged from a wide range of voltages, but also permits that recharging to take place in a controlled manner which can be predetermined by the manufacturer of the rechargeable cell. A further advantage of this arrangement is that if the rechargeable cell is a Nickel Cadmium rechargeable cell, which typically produces 1.2 Volts in use, the converter can boost this voltage to a terminal voltage of 1.5 V which is the voltage normally associated with a dry cell. The converter will not normally be running when the single cell battery pack is not in use to conserve the energy contained in the cell. The converter can be activated by the connection of a load across terminals 3 and 4. The current which flows as a result of the connection of this activates a transistor switch contained within the converter control system which initiates operation of the converter.

A variety of converter types have been identified as being suitable for use in this battery management arrangement. In any battery management arrangement the arrangement is not limited to a single type of converter. Different types of converter may be combined in a given battery arrangement. The type of converter used in a particular battery arrangement is not limited to the converters described herein but may include any type of converter with the appropriate characteristics.

CLAIMS

1. A power management apparatus for drawing power independently from a plurality of power sources (1), characterised in that at least one electronic converter (7) is connected to one of the power sources so as to draw power from the power source, voltage convert it to a desired value and to make it available for supply to a load.

2. A power management apparatus as claimed in claim 1, characterised in that a plurality of electronic converters (1) are provided, and the output of the converters are combined to form a single output.

3. A power management system as claimed in claim 1 or 2, characterised in that each converter (7) is associated with a respective power source.

4. A power management system as claimed in claim 1 to 3, characterised in that the electronic converter (7) employed is a boost converter.

5. A power management system as claimed in claims 1 to 3, characterised in that the electronic converter type employed is a forward converter operated in the current-controlled mode.

6. A power management system as claimed in claims 1 to 3, characterised in that the electronic converter (7) is a buck-boost converter.

7. A power management system as claimed in claims 1 to 3 characterised in that the electronic converter (7) is a fly-back converter.

8. A power management system as claimed in any one of claims 1 to 3, characterised in that the at least one converter (7) is operable in a step-up mode and a step-down mode.

9. A power management system as claimed in any one of the preceding claims, characterised in that the at least one converter (7) is arranged to permit bi-directional power flow such that it can remove energy from a power source or a storage device (1) or supply energy to a storage device.

10. A power management system as claimed in claim 1 characterised in that a single converter is employed (7), the converter being selectively connected to one of a plurality of batteries, the battery (1) to be used at any given time being chosen by means of a selector switch (5) either mechanical or electronic.

11. A power management system as claimed in any one of the preceding claims, characterised in that an auxiliary power source (9) provides the power for the control circuits of the at least one electronic converter (7).

12. A power management system as claimed in claim 11, characterised in that the auxiliary source also provides power for a system management unit.

13. A power management system as claimed in claim 12, characterised in that the auxiliary source (9) is a battery.

14. A power management system as claimed in claims 11, 12 or 13, characterised in that is an electronic converter (43) is provided to boost the output of the auxiliary source (9).

15. A power management system according to any one of the preceding claims , characterised in that a voltage control loop (20-29, 31) regulates the switching of the at least one electronic converter (7).

16. A power management system according to claim 15, characterised in that voltage control loop co-operates with at least one current control loop (32-36) to regulate the switching of the at least one electronic converter (7).

17. A power management system according to any one of the preceding claims, characterised in that a plurality of electronic converters are provided and the electronic converters maybe switched into or out of operation by a system management unit (40) according to a predetermined strategy of battery or other power source usage.

18. A power management system according to claim 17, characterised in that the predetermined strategy of battery or power source usage may be programmed by switches, push buttons or some other input means.

19. A power management system as claimed in any one of the preceding claims, characterised in that it has more than one output of different voltage.

20. A power management system as claimed in any one of the preceding claims, characterised in that the output voltage or voltages may be varied electronically in use by means of a control signal derived from the apparatus which the power management system supplies.

21. A power management system as claimed in any one of the preceding claims, characterised in that it is arranged to receive power from a plurality of sources, to monitor the current flowing from each source or from each converter, and to successively bring the converters into operation such that an Nth converter is started up when the current flow into or from an N-1th converter is at a predetermined value or when the current demand by the load is no longer being adequately provided.

22. A battery management system, characterised by including a power management system as claimed in any one of the preceding claims.

23. A battery management system as claimed in claim 22, characterised in that indicator lights (39) or some other form of visual indicator are provided to show the state of charge of the batteries and/or to indicate which batteries (1) are being used as a source of power.

24. A battery store in combination with a battery management system as claimed in any one of claims 22 or 23.

25. A combination as claimed in claim 24, characterised in that the battery management system is arranged to charge the batteries.

26. A module or battery pack which contains at least one battery, the or each of which has an associated converter circuit so as to draw power from the or each battery, voltage convert it to a desired value and to make it available for supplying a load.

27. A method of extracting energy from power sources, comprising the steps of associating a plurality of power sources with at least one voltage converter, and voltage converting the output of the sources to a desired value.

28. A power management system as claimed in claim 1, in which one of the sources is a capacitor (300) and the management system is arranged to control the storage of energy to and removal of energy from the capacitor.

29. A power management system as claimed in claim 28, characterised in that one of the sources is a mechanical generator and the management system is arranged to control the flow of energy from the generator to a load and/or to the capacitor (300).

30. A power management system as claimed in claim 28 or 29, characterised in that the management system is in combination with a rechargeable battery, and in that the management system is arranged to control power transfer from the capacitor (300) to the battery.

31. A power management system as claimed in claim 30, characterised in that the capacitor is used as a temporary store of energy.

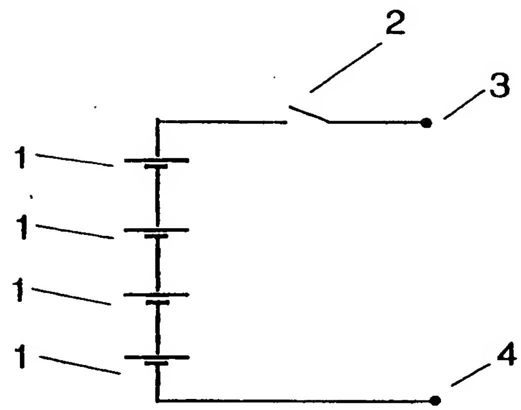


FIG. 1

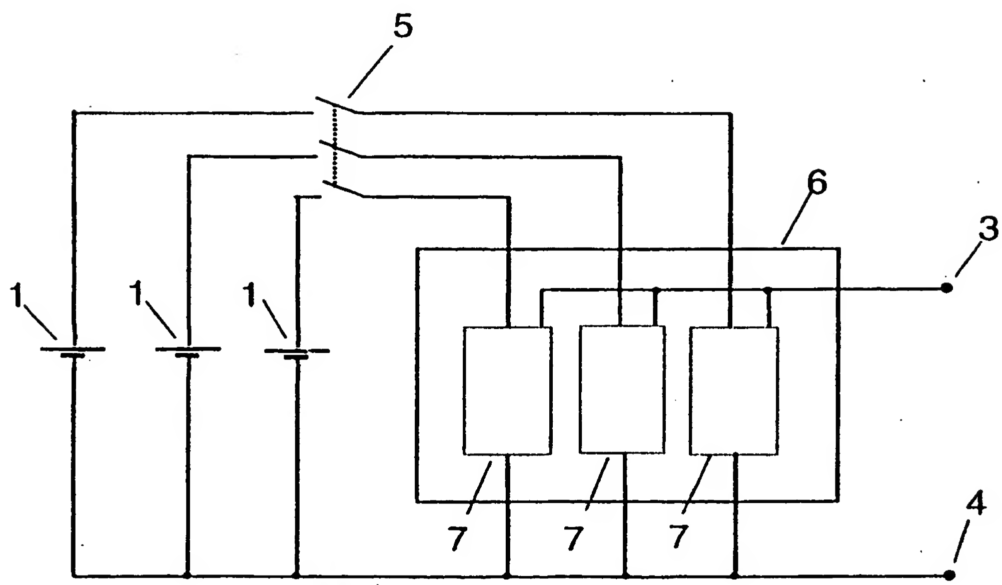


FIG. 2

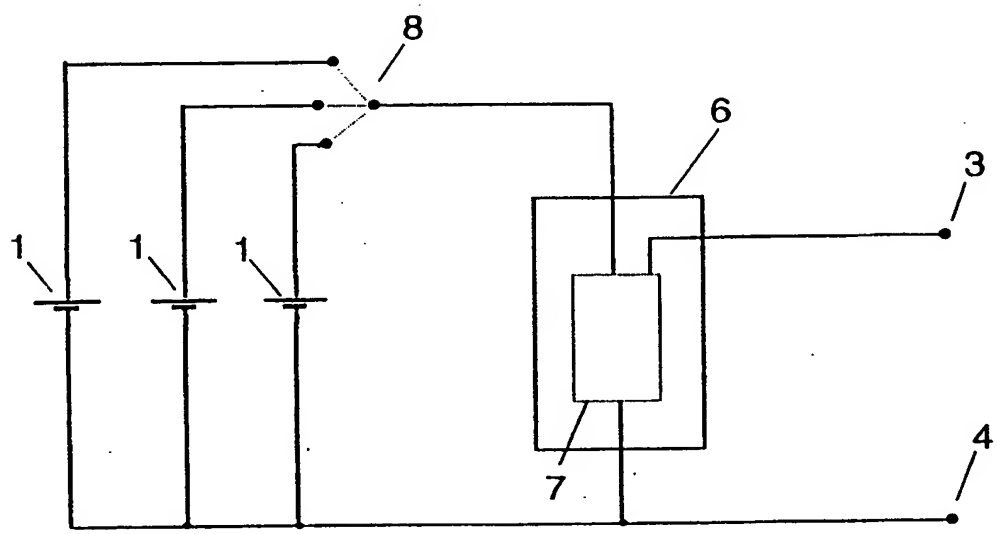


FIG. 3

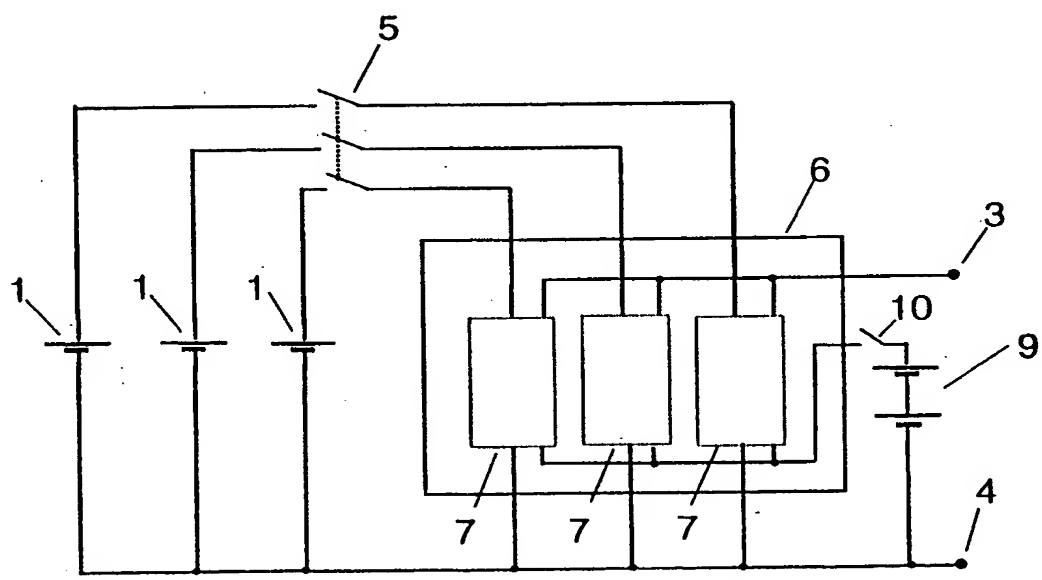


FIG 4

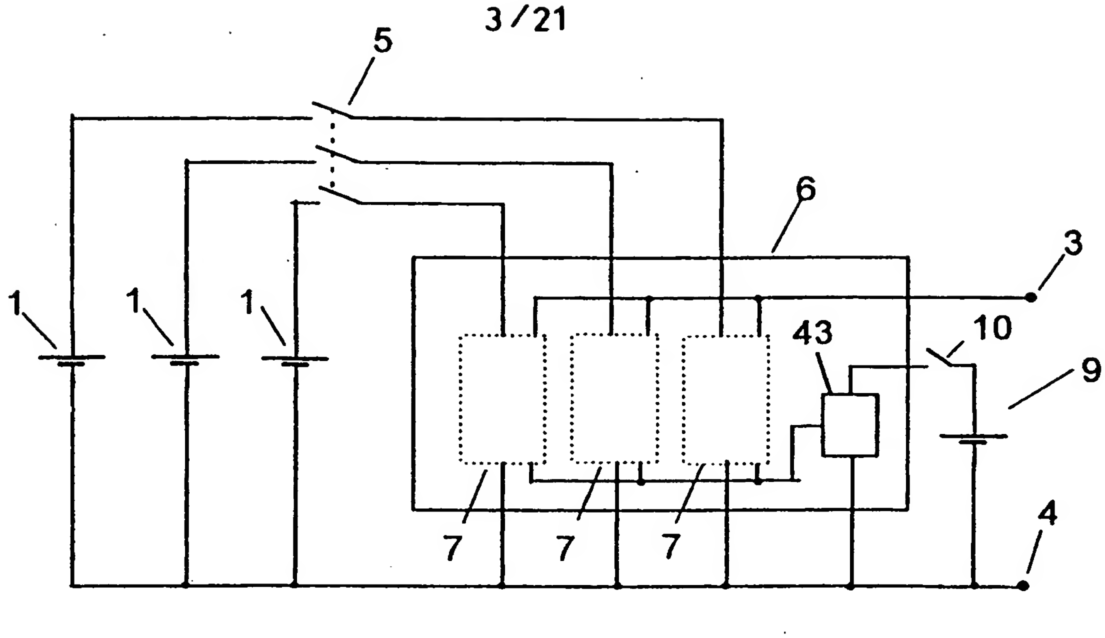


FIG 5

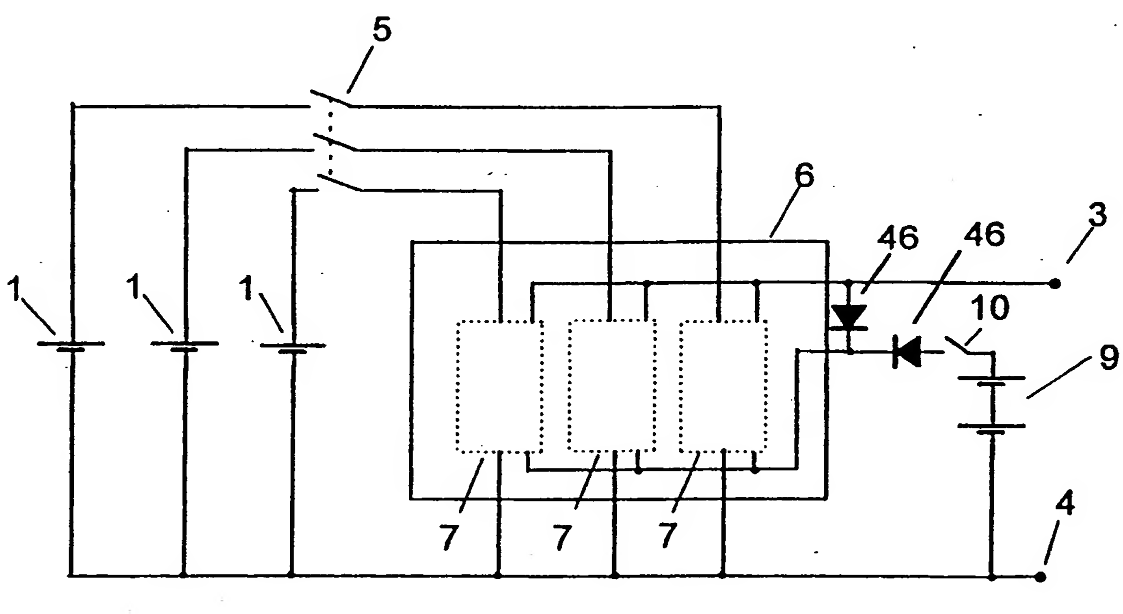


FIG 6

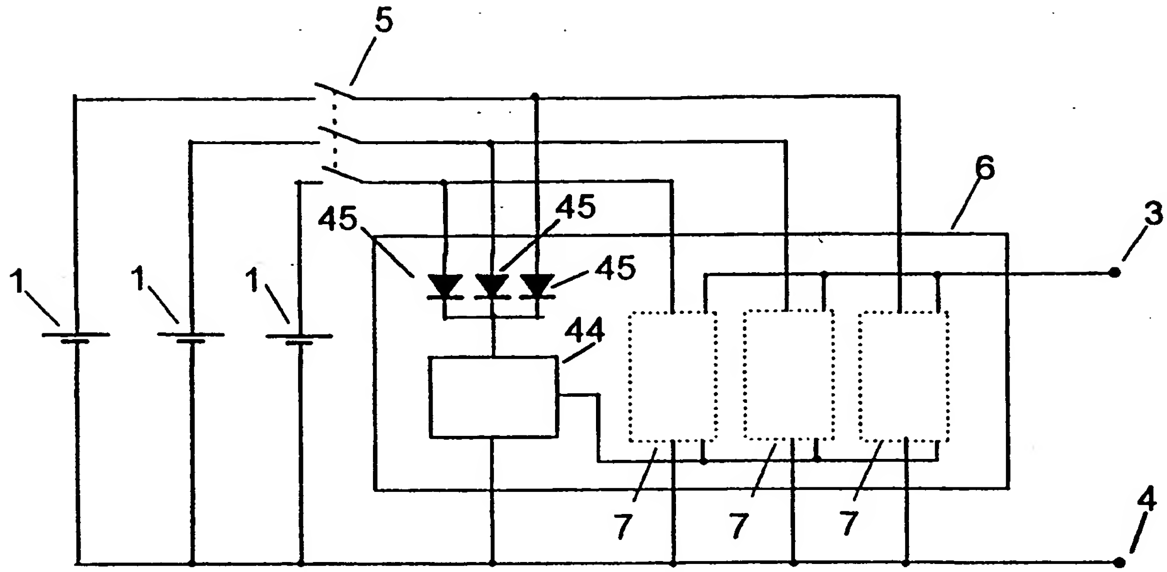
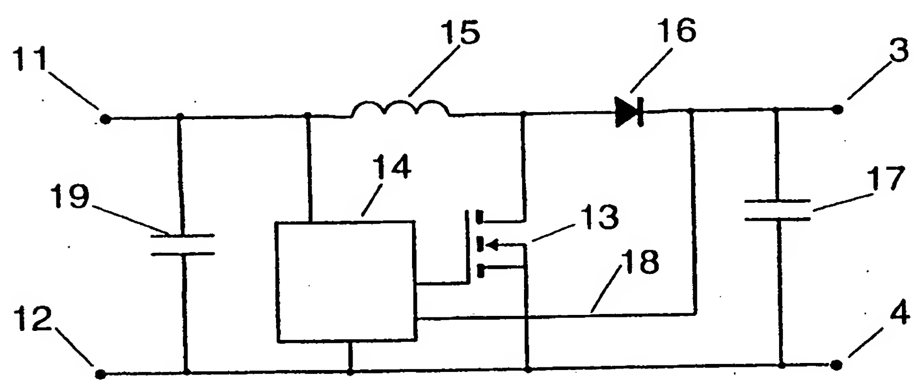


FIG 7



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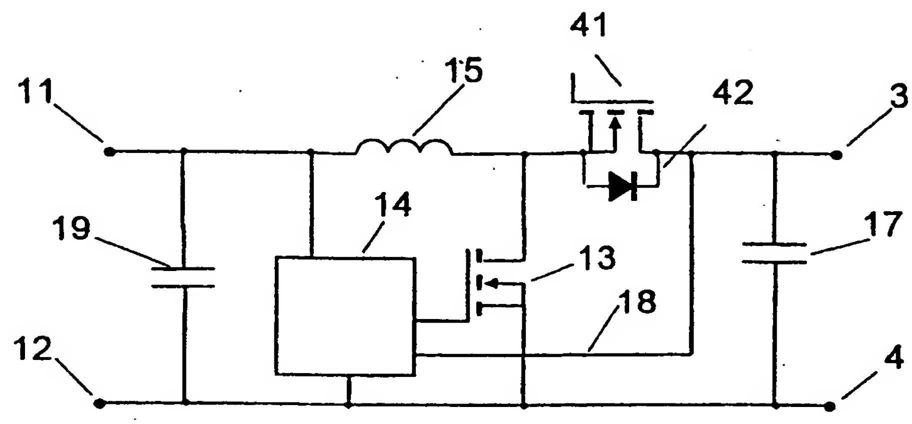


FIG 9

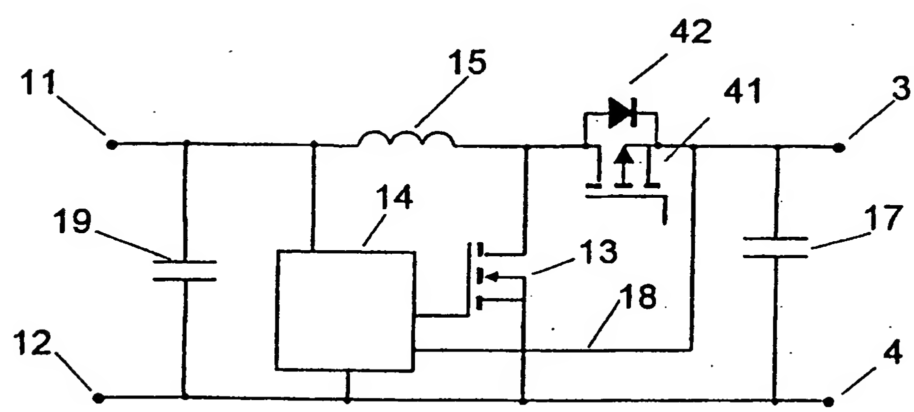
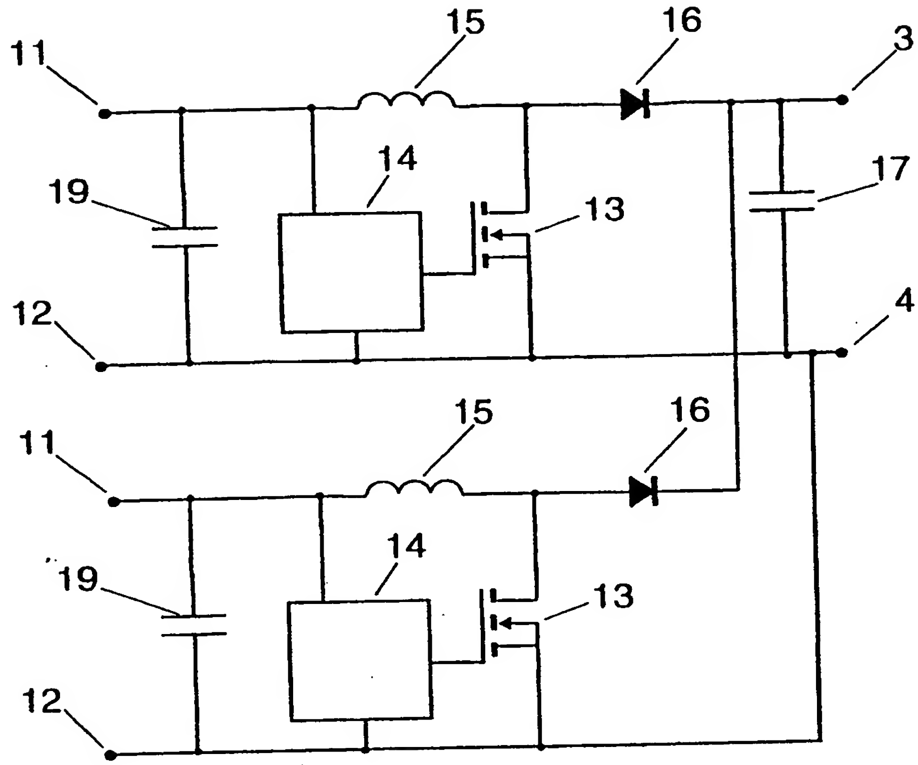


FIG 10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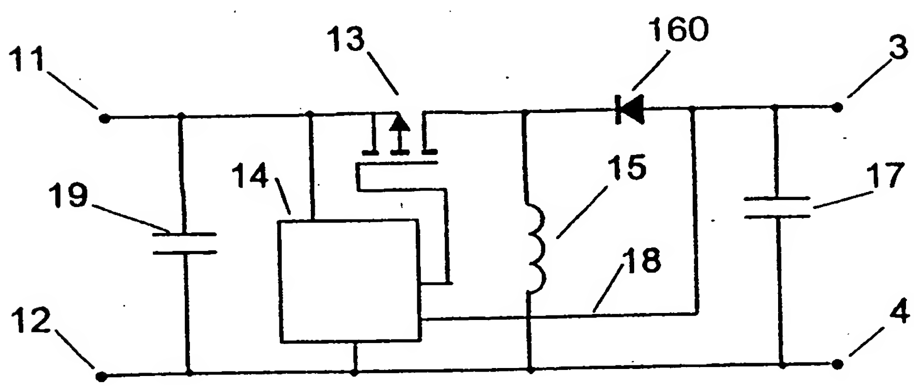
12

FIG. 11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4

FIG 12

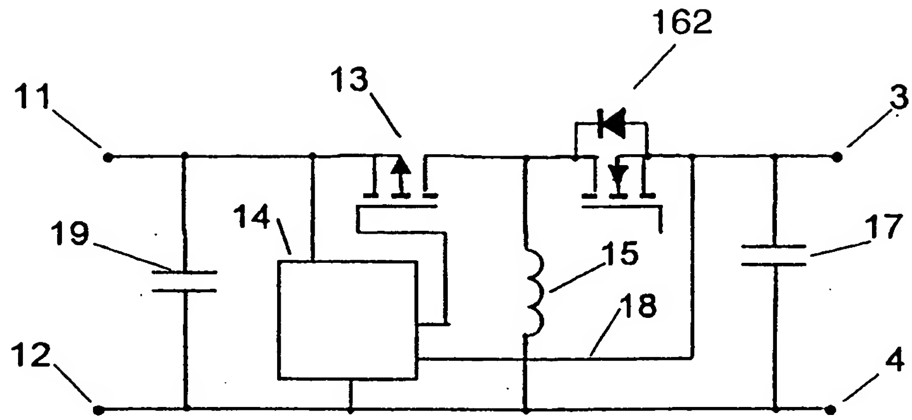


FIG 13

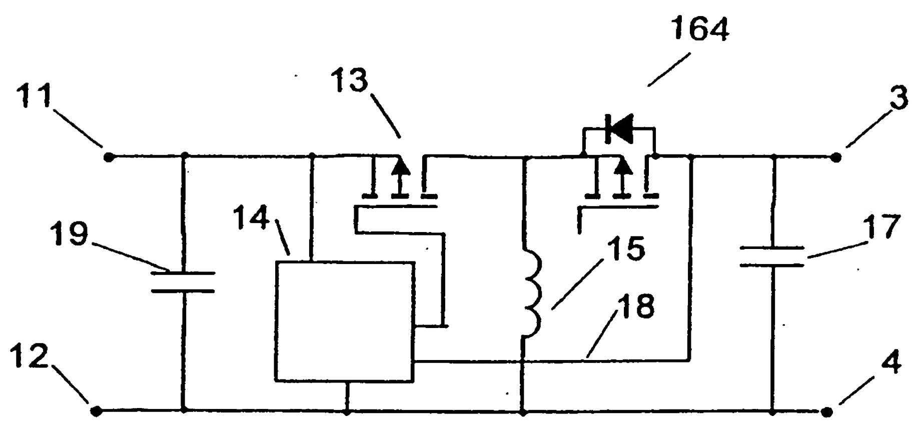


FIG 14

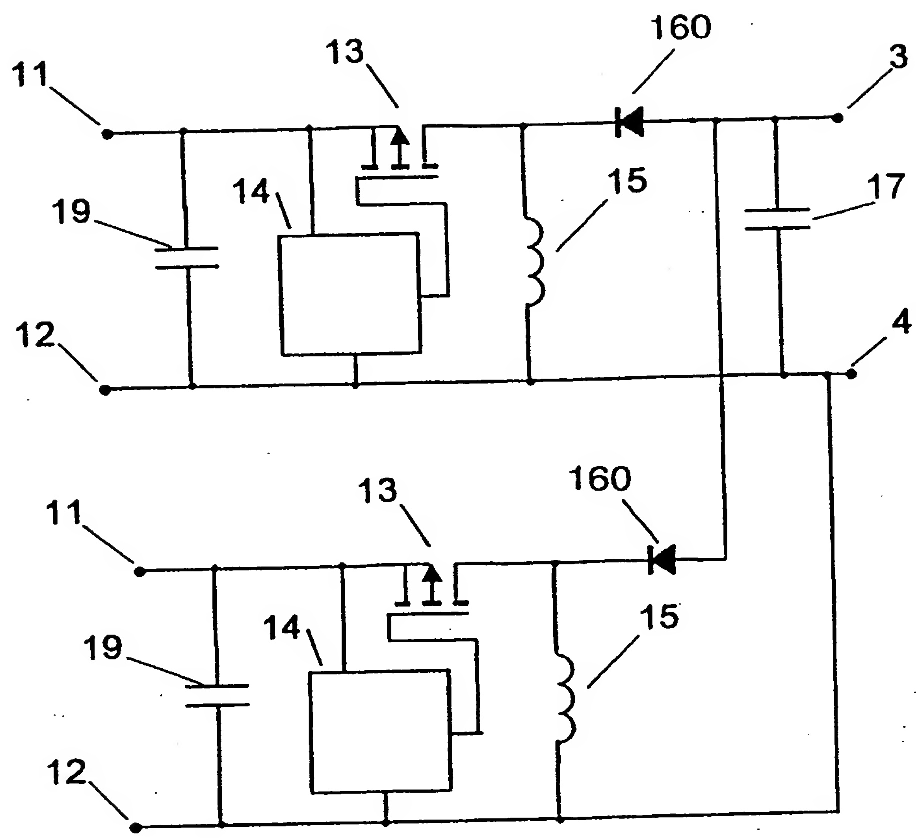


FIG 15

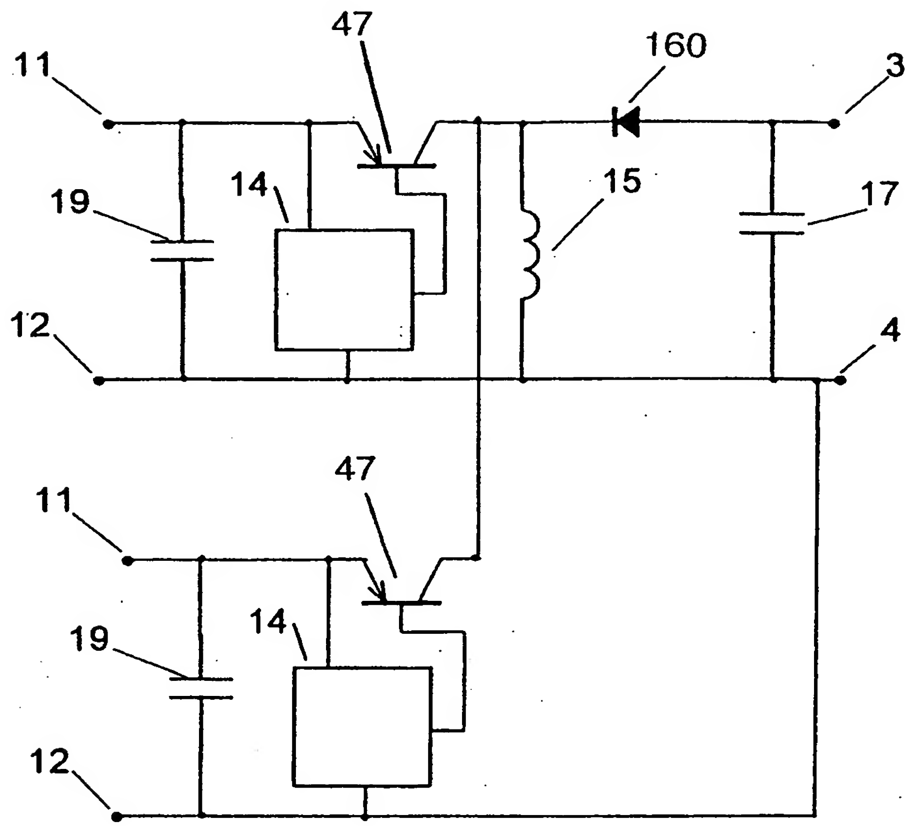
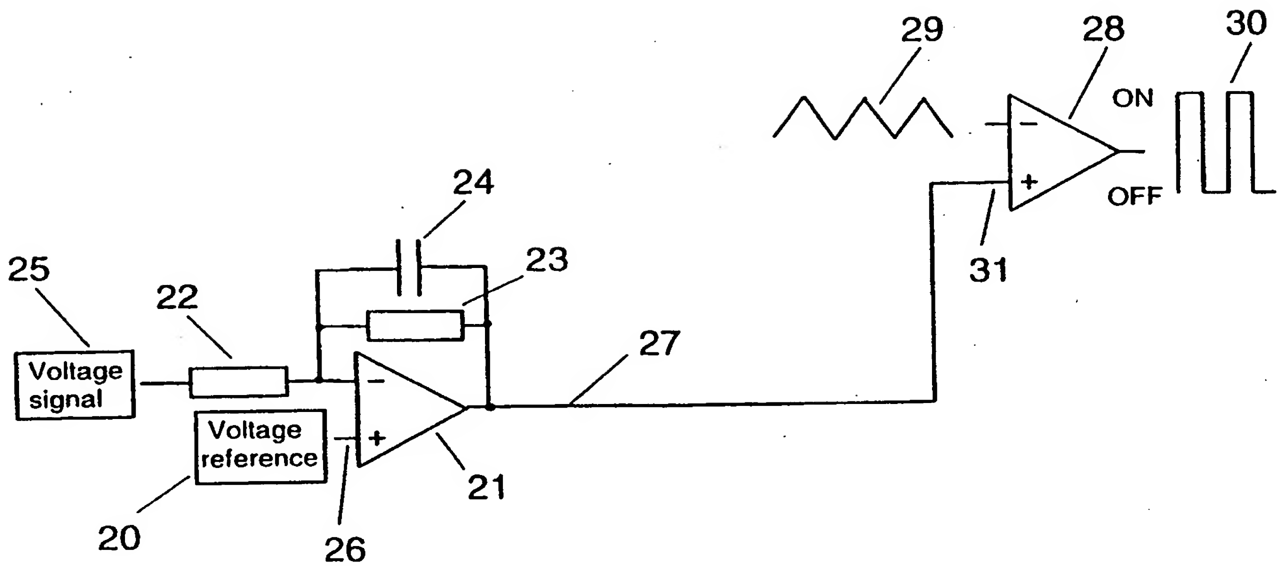


FIG 16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28
30
ON
OFF
24
23
25
22
31
27
Voltage signal
Voltage reference
21
20
26

FIG. 17

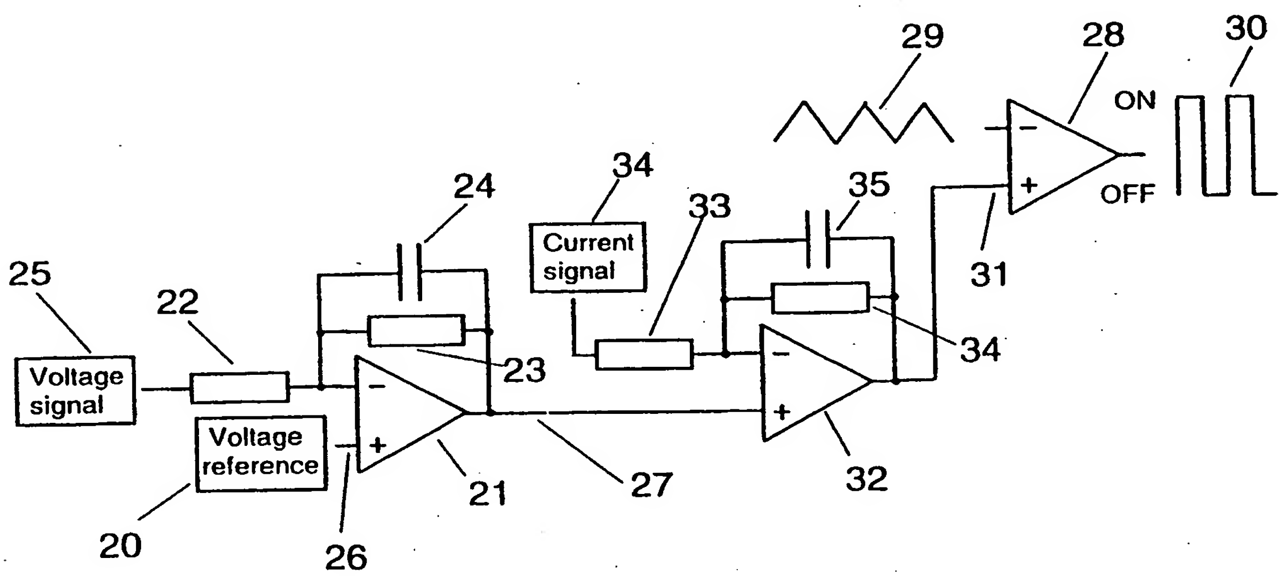
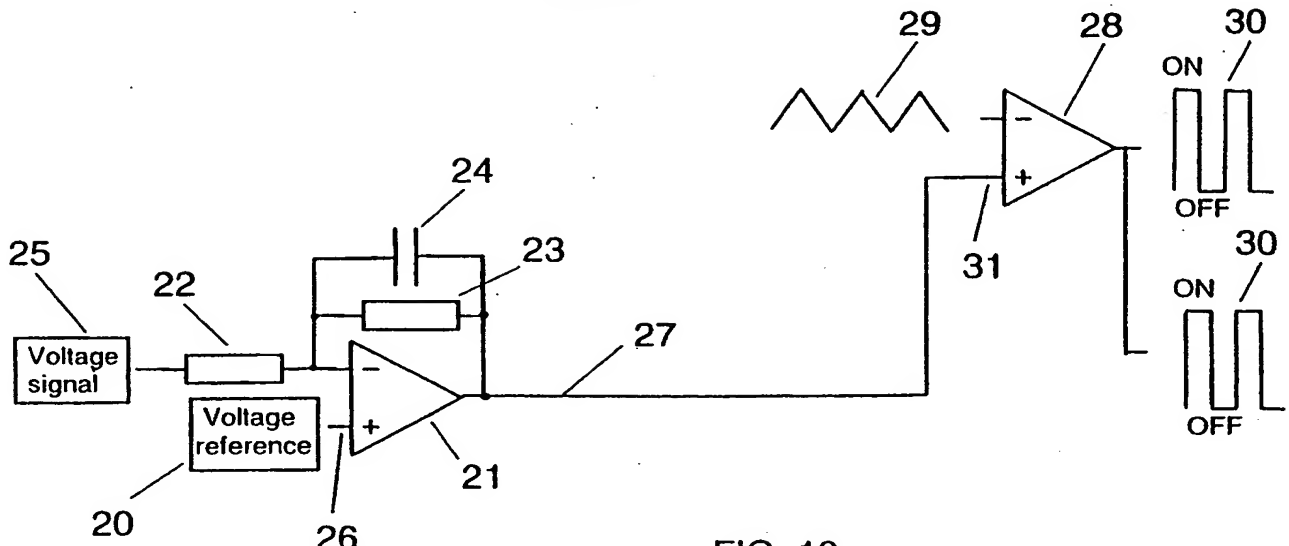

29
28
30
ON
OFF
34
24
Current signal
33
35
25
22
31
34
Voltage signal
23
Voltage reference
21
27
32
20
26

FIG. 18


29
28
30
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OFF
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23
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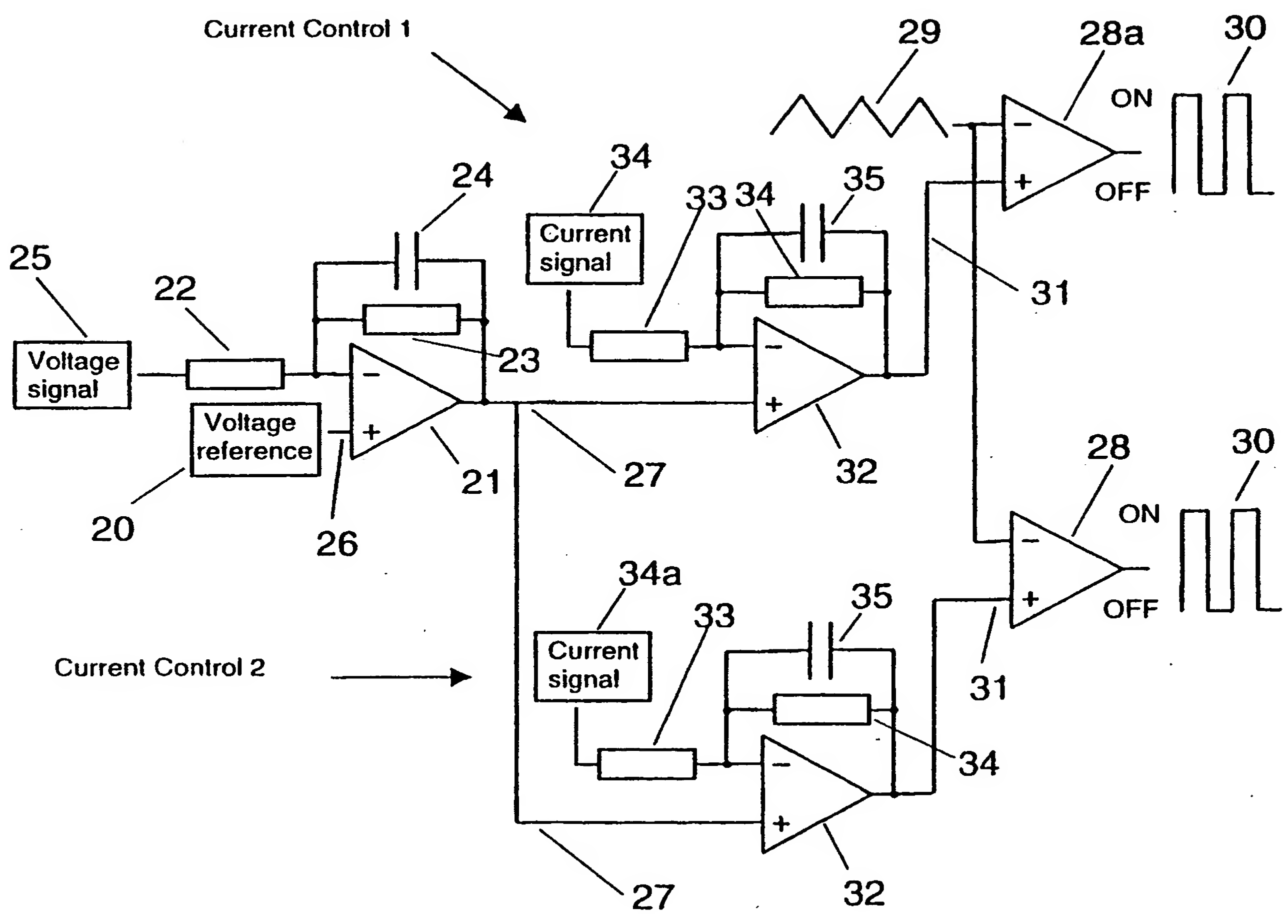
22
30
ON
31
27
Voltage signal
Voltage reference
OFF
21
20
26

FIG. 19


Current Control 1
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28a
30
ON
OFF
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Current signal
33
34
35
24
25
22
31
Voltage signal
23
Voltage reference
27
21
32
20
26
28
30
ON
34a
35
OFF
33
Current signal
31
Current Control 2
34
27
32

FIG. 20

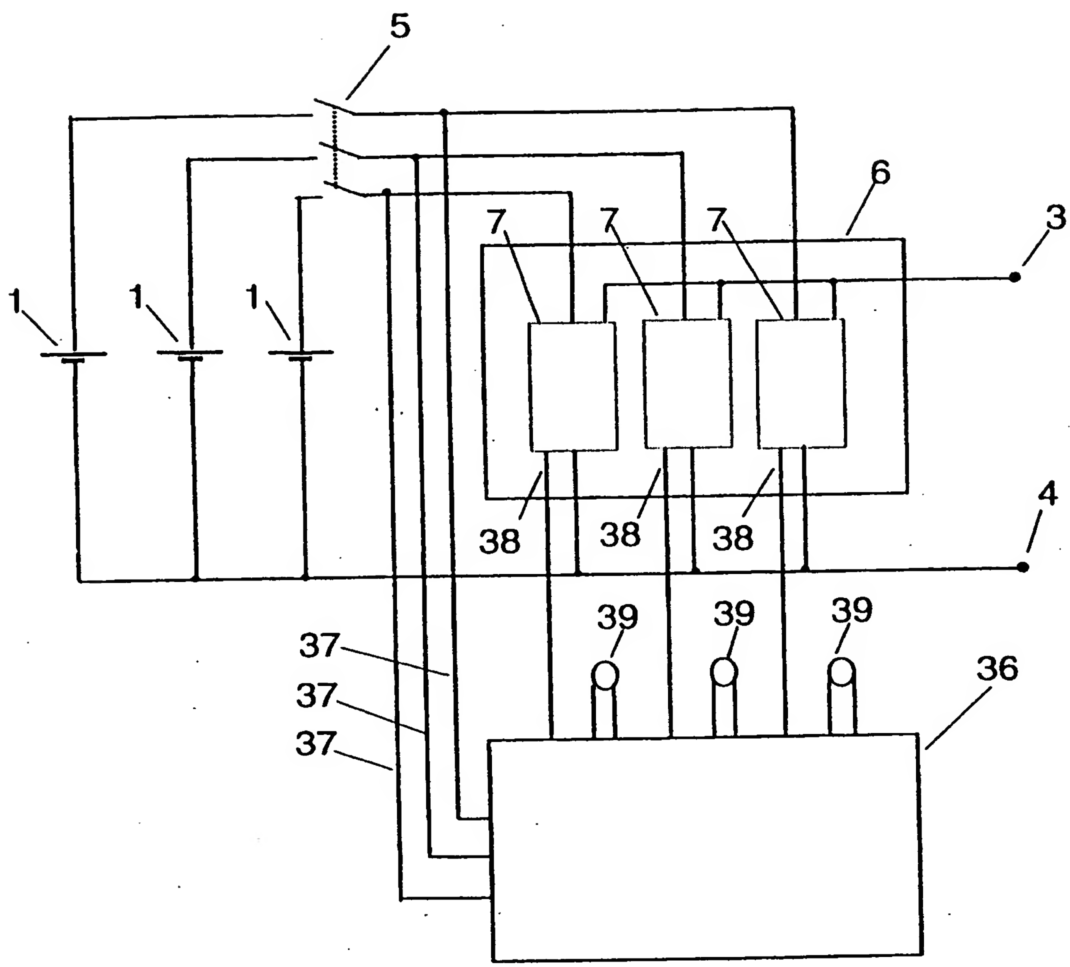


FIG. 21

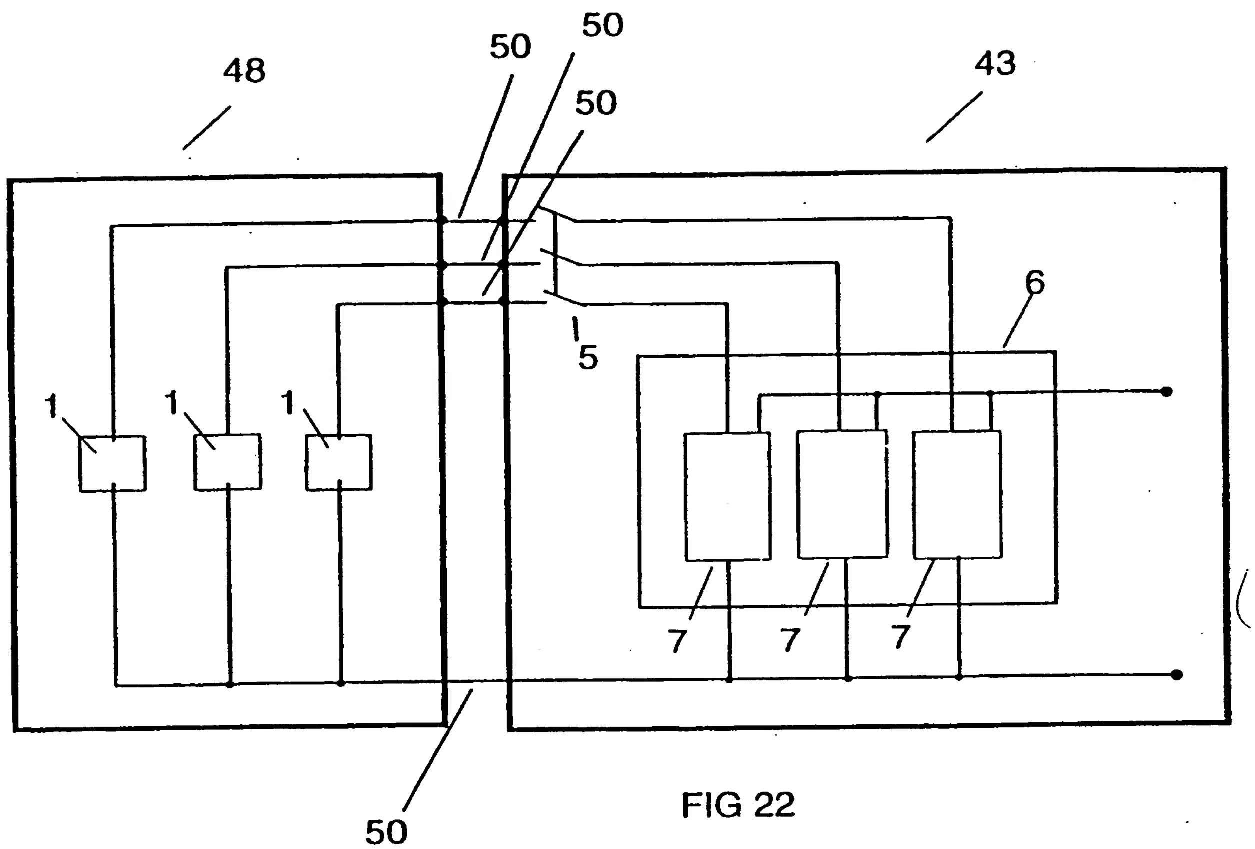


FIG 22

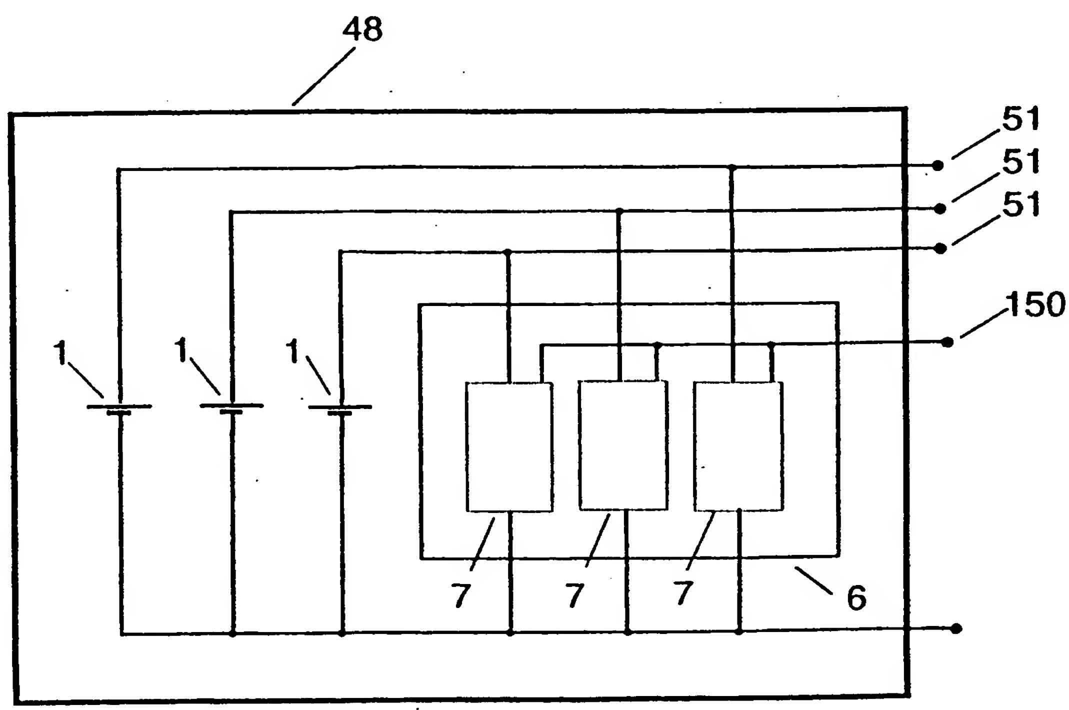


FIG 23

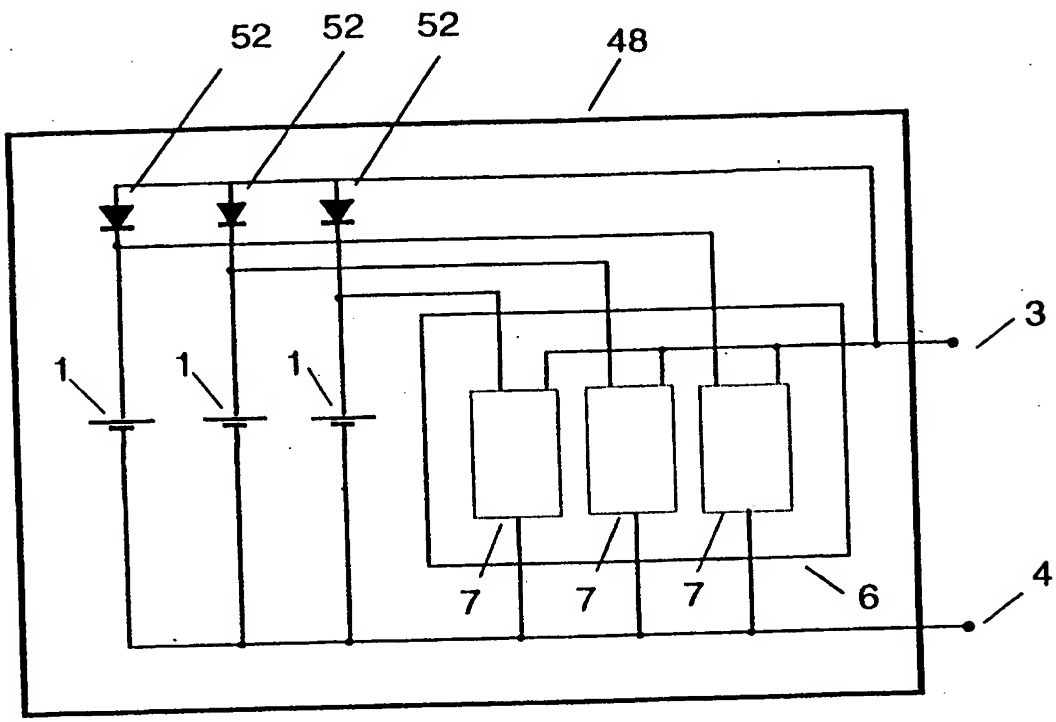


FIG 24

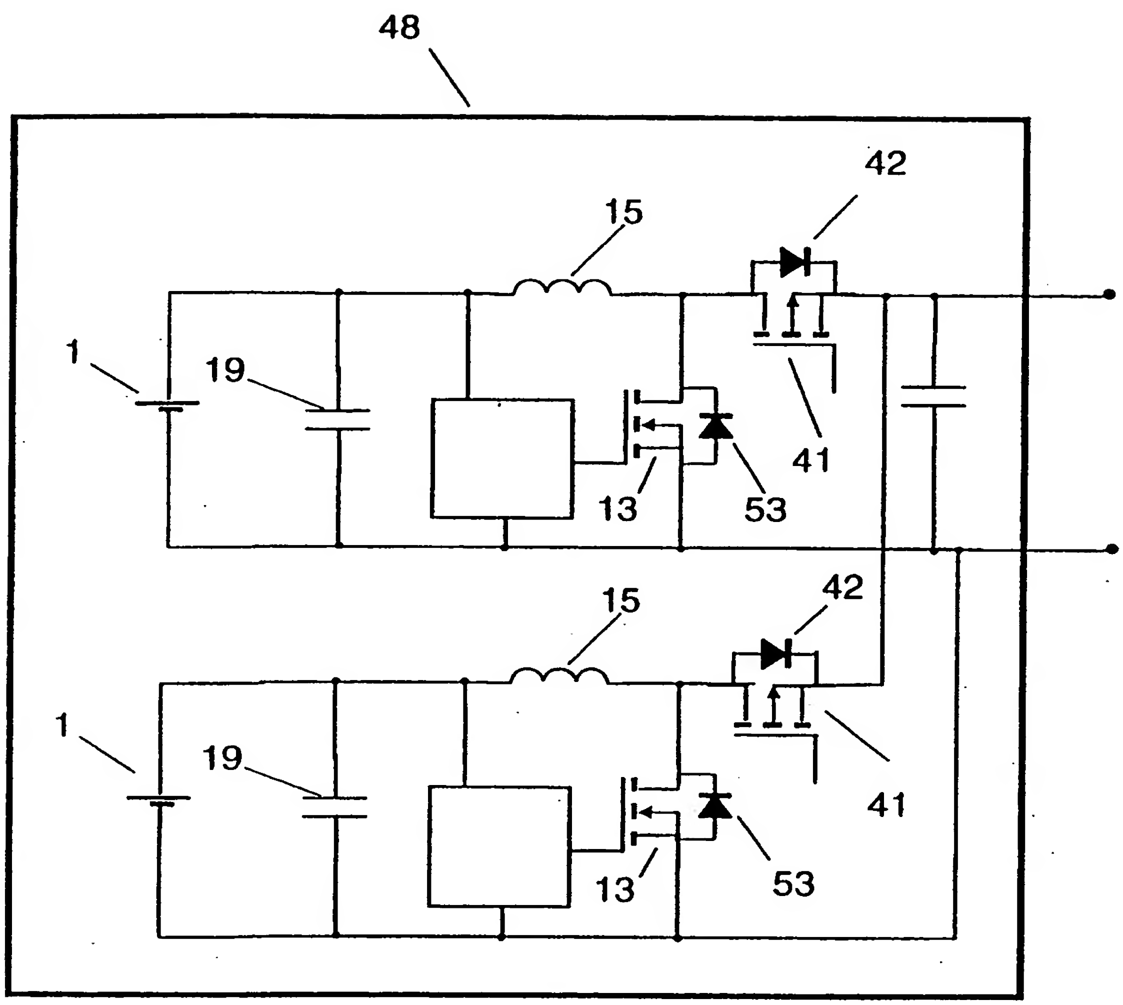


FIG. 25

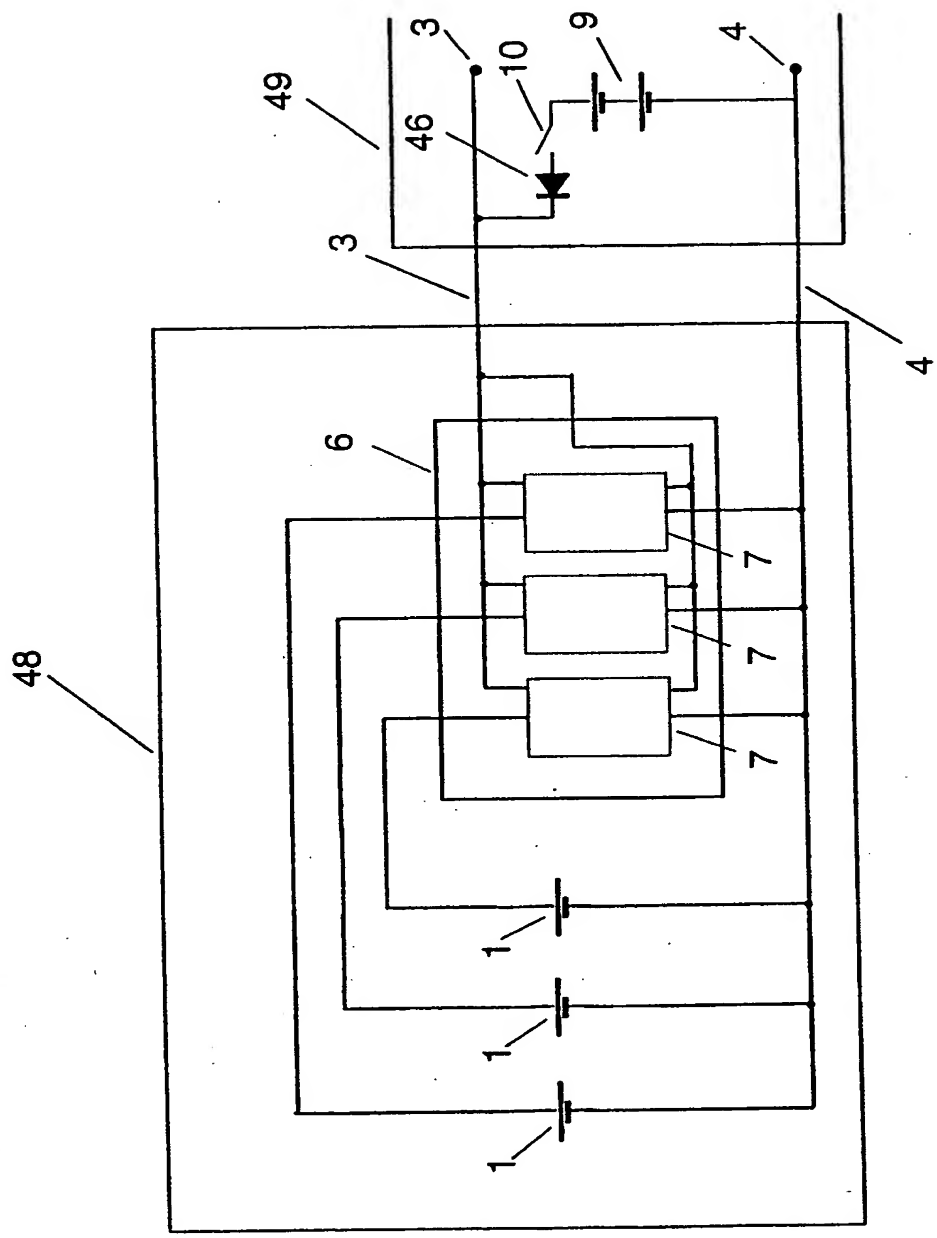
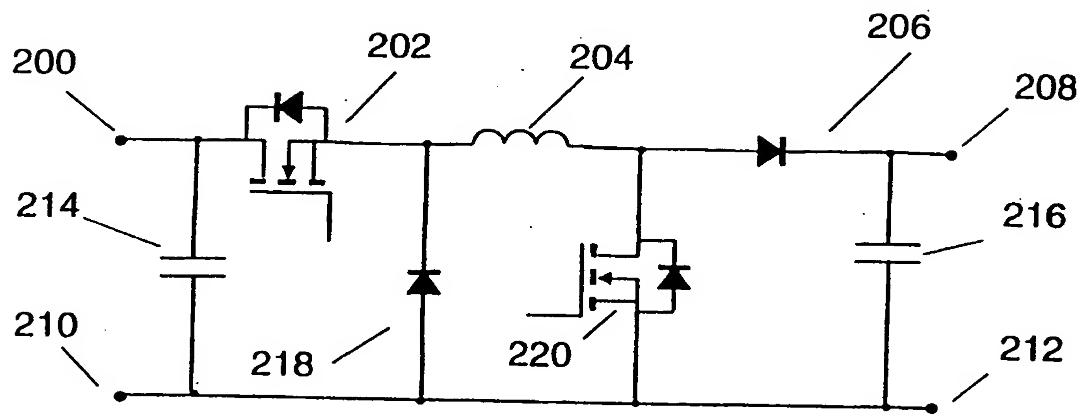


FIG. 26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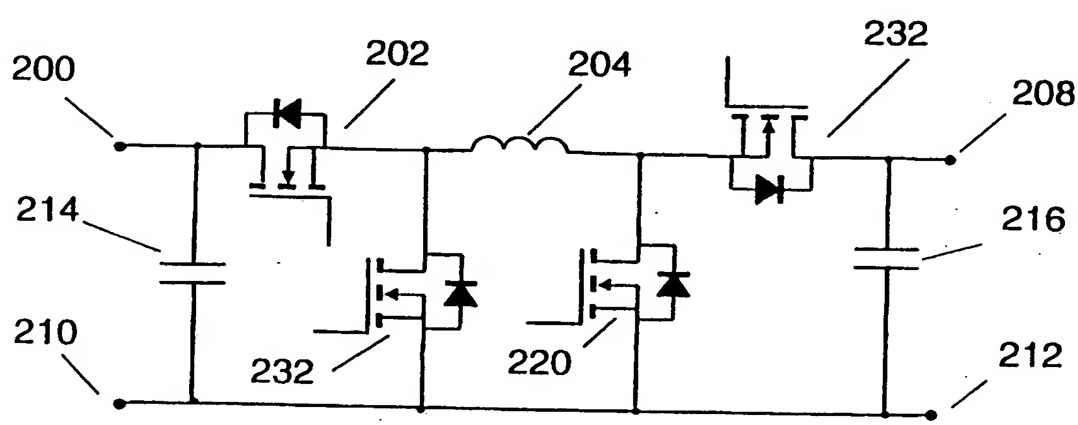
212

FIG. 27


200
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212

FIG. 28

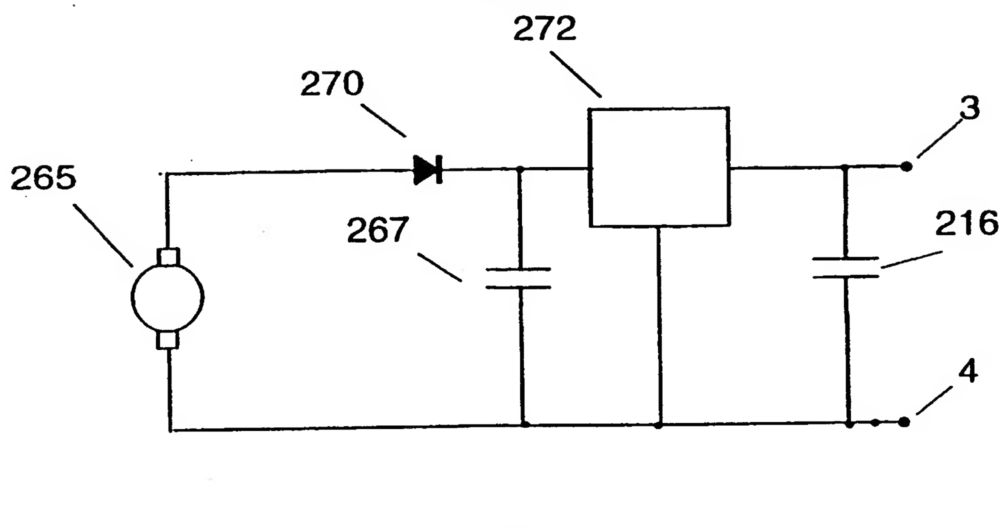

FIG. 29

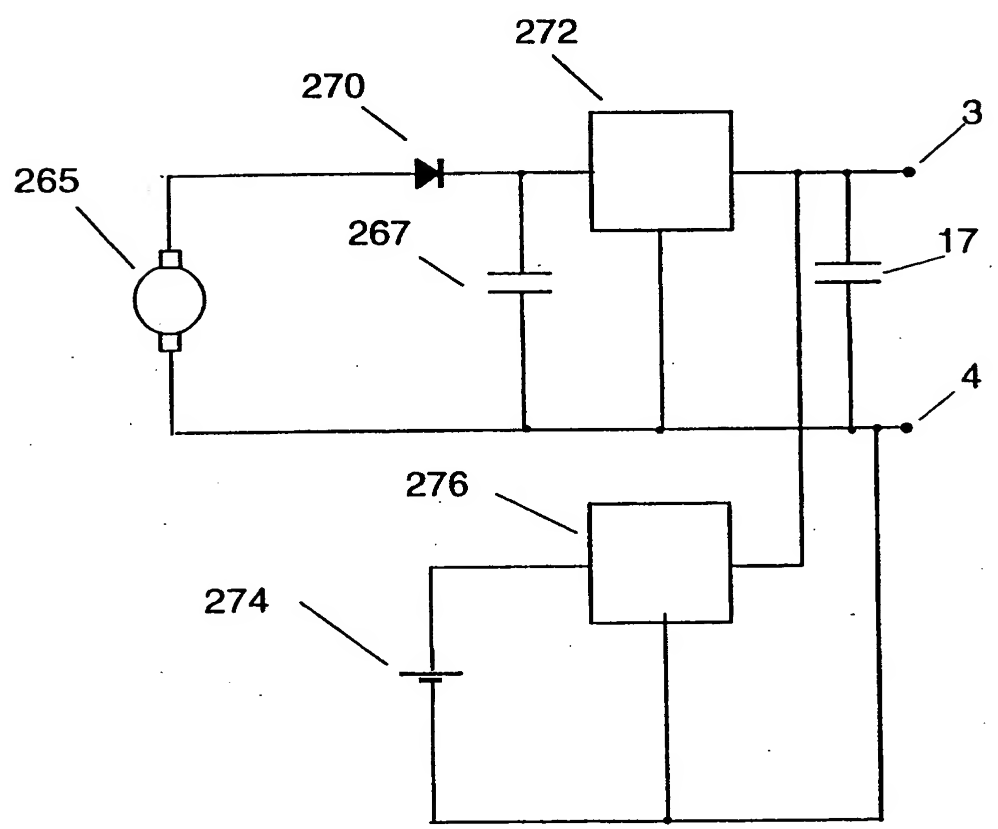

FIG. 30

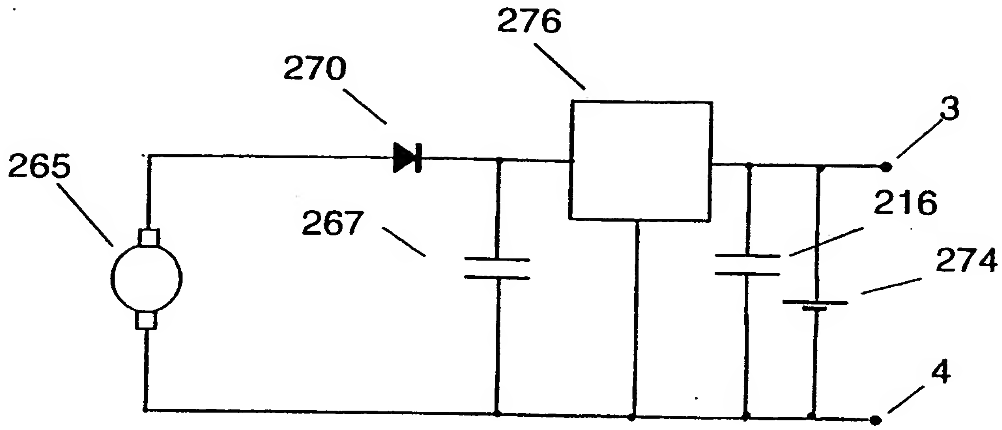

FIG. 31

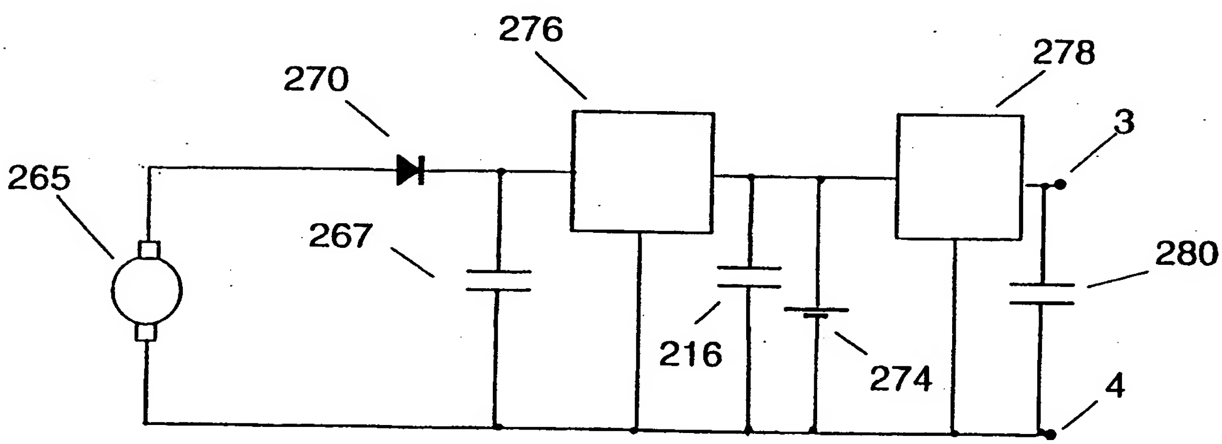

FIG. 32

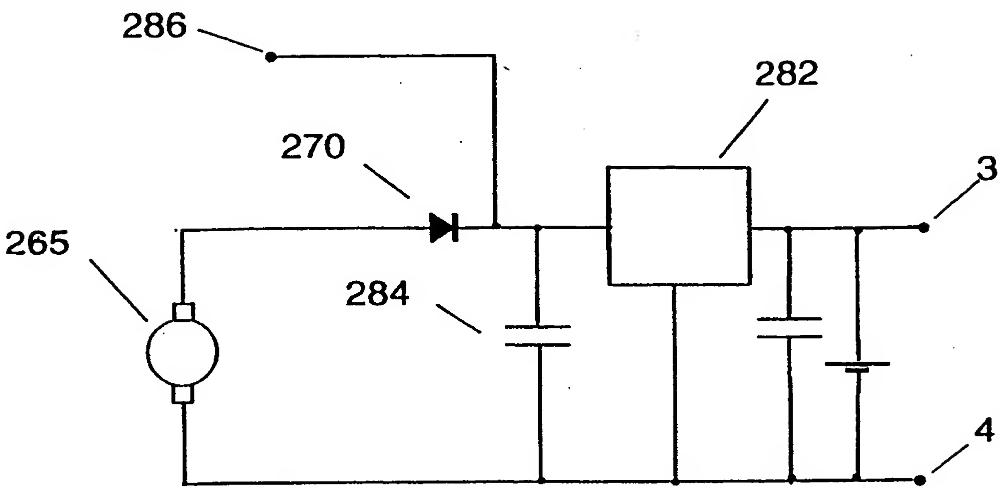
286
282
270
3
265
284
4

FIG. 33

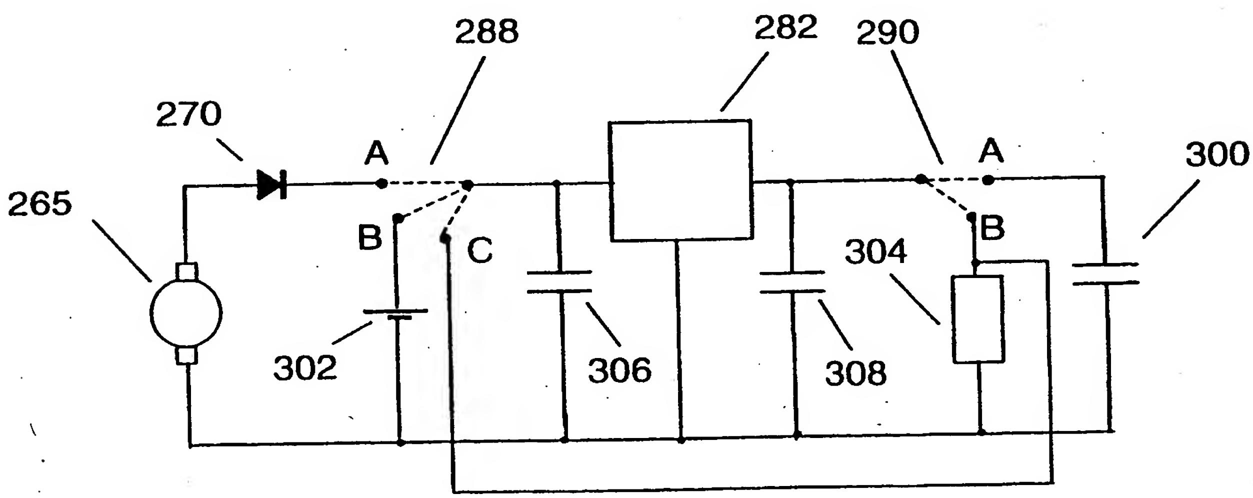
288
282
290
270
A
A
300
265
B
C
B
304
302
306
308

FIG. 34

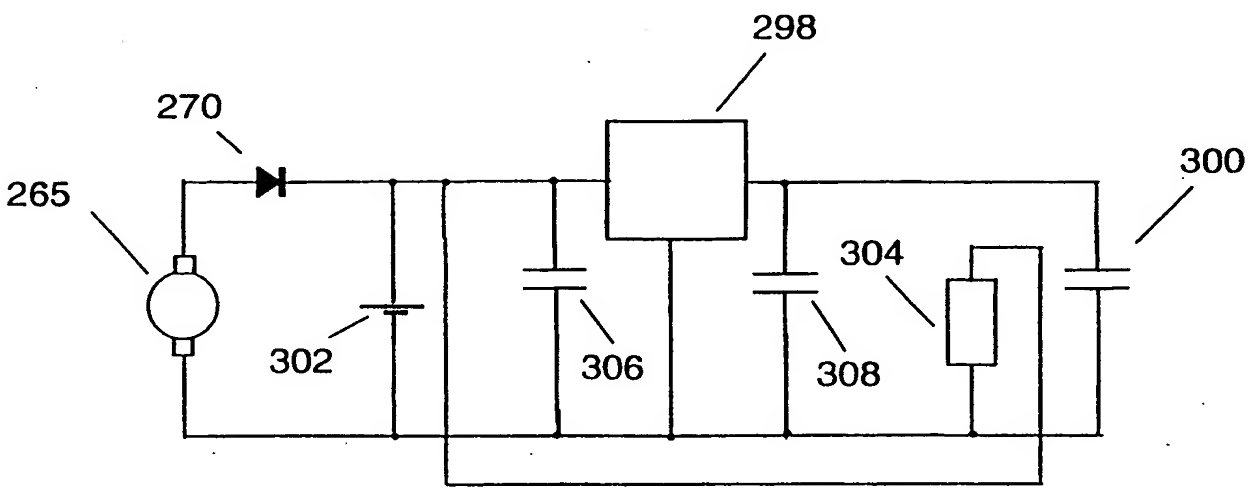

FIG. 35

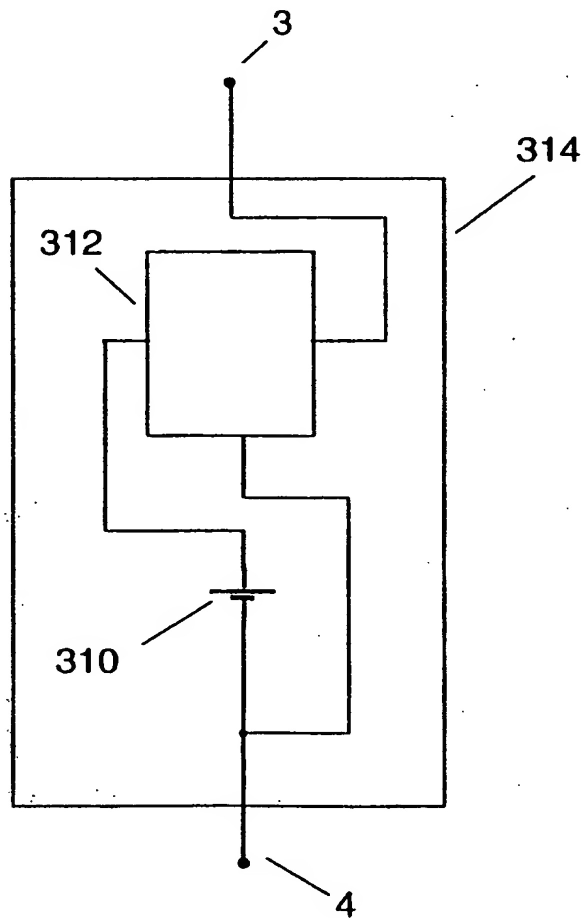

FIG. 36

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 99/03251

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H02J1/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H02J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 18, no. 137 (E-1518), 7 March 1994 (1994-03-07) & JP 05 316721 A (FUJITSU LTD), 26 November 1993 (1993-11-26) abstract & US 5 583 753 A (TORMIO TAKAYAMA) the whole document ---	1-31
A	EP 0 608 788 A (ALCATEL STANDARD ELECTRICA) 3 August 1994 (1994-08-03) abstract column 1, line 3 - line 34 column 2, line 26 - line 31 column 3, line 6 - line 20 ---	5

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 January 2000	01/02/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	Lund, M

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INTERNATIONAL SEARCH REPORT

Inter nal Application No
PCT/GB 99/03251

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 373 195 A (RIK W.A.A. DE DONCKER ET AL.) 13 December 1994 (1994-12-13) abstract figures 2,4 column 1, line 57 -column 2, line 4 column 3, line 43 - line 54 column 5, line 15 - line 37 ---	6,9,21
A	PATENT ABSTRACTS OF JAPAN vol. 17, no. 494 (E-1428), 7 September 1993 (1993-09-07) & JP 05 122865 A (NIPPON ELECTRIC) abstract ---	8
A	PATENT ABSTRACTS OF JAPAN vol. 1998, no. 14, 31 December 1998 (1998-12-31) & JP 10 243642 A (MATSUSHITA ELECTRIC), 11 September 1998 (1998-09-11) abstract ---	8
A	WO 96 00999 A (FRAUNHOFER-GESELLSCHAFT ZUR FÖRDERUNG DER ANGEWANDTEN FORSCHUNG) 11 January 1996 (1996-01-11) abstract figure 1 page 3, line 14 - line 23 ---	9
A	US 5 682 303 A (STEPHEN D. GOAD) 28 October 1997 (1997-10-28) abstract figures 1,2 column 1, line 21 - line 23 column 4, line 7 - line 28 column 5, line 38 - line 41 ---	10,21
A	US 5 428 523 A (JOHN E. MCDONNAL) 27 June 1995 (1995-06-27) abstract column 1, line 50 -column 2, line 68 ---	21
A	GB 2 260 040 A (JEN JONG CHEN) 31 March 1993 (1993-03-31) abstract figure 1 ---	23
A	PATENT ABSTRACTS OF JAPAN vol. 16, no. 454 (P-1425), 21 September 1992 (1992-09-21) & JP 04 160419 A (MATSUSHITA ELECTRIC), 3 June 1992 (1992-06-03) abstract --- -/--	23

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Interr ıal Application No
PCT/GB 99/03251

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	WO 97 01213 A (D.C. TRANSFORMATION INC.) 9 January 1997 (1997-01-09) abstract figures 1,5,7,8,11 ---	28-31
A	PATENT ABSTRACTS OF JAPAN vol. 6, no. 37 (E-97), 6 March 1982 (1982-03-06) & JP 56 153985 A (MATSUSHITA ELECTRIC WORKS), 28 November 1981 (1981-11-28) abstract -----	28-31

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 99/03251

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JP 04160419 A	03-06-1992	NONE	
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